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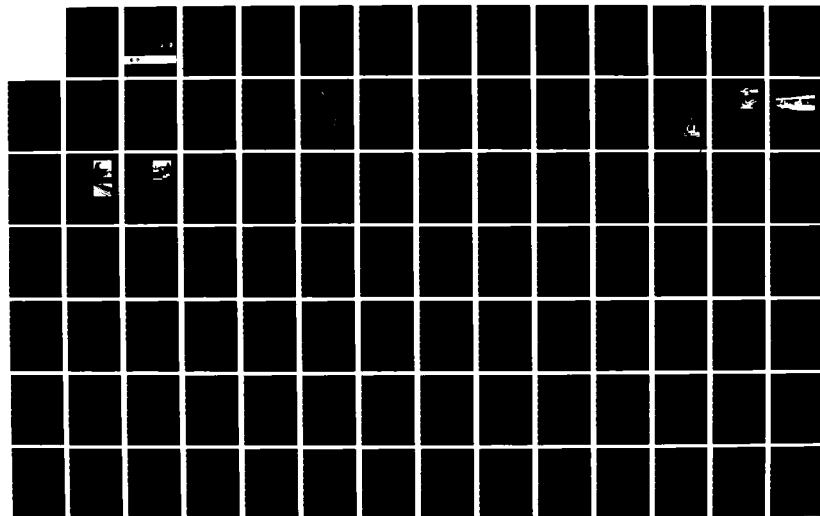
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AD-A162 084

# **Movement of Tagged Dredged Sand at Thalweg Disposal Sites in the Upper Mississippi River**

Volume 3:  
Additional Results at Gordon's Ferry  
and Whitney Island Sites

D. L. McCown and R. A. Paddock

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This informal report presents preliminary results of ongoing work or work that is more limited in scope and depth than that described in formal reports issued by the Energy and Environmental Systems Division.

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**ANL/EES-TM-270, Vol. 3**

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**MOVEMENT OF TAGGED DREDGED SAND AT THALWEG  
DISPOSAL SITES IN THE UPPER MISSISSIPPI RIVER  
VOLUME 3: ADDITIONAL RESULTS AT GORDON'S FERRY  
AND WHITNEY ISLAND SITES**

by

**D.L. McCown and R.A. Paddock**

**Energy and Environmental Systems Division  
Geoscience and Engineering Group**

**April 1985**

work sponsored by

**U.S. DEPARTMENT OF DEFENSE  
Army Corps of Engineers  
Rock Island District**

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## FOREWORD

Argonne National Laboratory and the U.S. Army Corps of Engineers, Rock Island District, have undertaken a four-year investigation of main-channel, or thalweg, disposal of sand dredged during maintenance of the navigation channel in the Upper Mississippi River. During a routine dredging operation, hydraulically dredged sand was tagged with dyed sand and returned to the river channel downstream of the dredging site. The tagged dredged sand initially formed a pile along the thalweg of the river. Subsequent monitoring, which included sampling surficial bottom sediments and measuring bathymetry, was used to study the movement of the tagged sand in the river.

In a series of preliminary studies, Argonne evaluated alternative sampling and detection procedures for identifying tagged sand in the river environment. These preliminary studies are discussed in *Sampling and Detection of Tagged Dredged Material* (ANL/EES-TM-169), which was published in January 1982.

A full-scale experiment was first carried out in the fall of 1981 during a routine dredging operation at a site near Gordon's Ferry, about 23 km downstream of Dubuque, Iowa. Experience gained at this first site was used to refine the experimental procedures, and a second experiment was initiated at the Whitney Island site near Hannibal, Missouri, in the fall of 1982. The experimental procedures and the results from surveys at these first two sites through June 1983 are discussed in ANL/EES-TM-270, Vol. 1.

A third experiment using a dyed-sand tracer was initiated at the Savanna Bay site near Savanna, Illinois, in the fall of 1983. In addition, bathymetric measurements were carried out at a fourth thalweg disposal site near Duck Creek, about 24 km upstream of the Savanna Bay site, to monitor changes in the physical structure of the disposal pile. The results from surveys at these second two sites over a nine-month period are presented in ANL/EES-TM-270, Vol. 2. Results from additional surveys at Gordon's Ferry and Whitney Island through the fall of 1984, including results from analyzing bottom cores taken at the Gordon's Ferry site during the summer of 1983, are reported in this volume.



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The support provided by the Rock Island District of the U.S. Army Corps of Engineers exceeded simply funding the project. Henry Pfiester, Chief of Operations, participated in formulating the initial experimental plans and saw to it that we had access to logistical support from the District. Richard Baker, Chief of Channel Maintenance, Operations, often joined us in the field and provided valuable information regarding local river conditions. George Wells, the present project manager, was always available to provide access to groups within the Corps when their assistance was needed. The Hydraulics Regulation Branch supplied the water-level and flow data.

The progress of this research was reviewed regularly by two units of the Great River Environmental Action Team: the River Resources Coordinating Team, chaired by George Wells of the District, and the On-Site Inspection Team, chaired by Gail Peterson of the U.S. Fish and Wildlife Service. Their questions, comments, and support are appreciated.

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**ABSTRACT**

During routine channel maintenance, hydraulically dredged sand was tagged with sand coated with fluorescent dye before being deposited as a pile in the thalweg at three sites on the Upper Mississippi River. As discussed in the first two volumes of this report, bathymetry was measured and surface sediments were sampled to study changes in the topography of the disposal pile and the downstream movement of the tagged sand. At all three sites, topographic evidence of the pile disappeared after the first period of high river flow, which was followed by redevelopment of dunes in the disposal area. The tagged sand did not migrate into nearby border areas, backwaters, or sloughs, remaining in the main channel as it moved downstream.

This volume presents the results of additional surveys at the Gordon's Ferry and Whitney Island sites. At Gordon's Ferry, 25 bottom cores were taken to examine the three-dimensional distribution of tagged sand in the bottom sediments. The core analyses indicated that much of the tagged sand had been incorporated into the dune structure and that it resided primarily in the crests of the dunes.

**1 INTRODUCTION**

The downstream movement of dredged material deposited in the Upper Mississippi River has been the focus of a study conducted by Argonne National Laboratory for the U.S. Army Corps of Engineers, Rock Island District. Large-scale field experiments were conducted at four sites. During routine channel maintenance at the Gordon's Ferry, Whitney Island, and Savanna Bay sites, hydraulically dredged sand was tagged with sand coated with fluorescent dye and returned to the main river channel, or thalweg, downstream of the dredging site. The tagged dredged sand initially formed a pile along the thalweg. The downstream movement of the tagged sand and the changing structure of the disposal pile were monitored by sampling surface sediments and measuring bathymetry. Dyed sand was not used at the fourth site, Duck Creek, where bathymetric measurements alone were used to monitor changes in the disposal pile.

The experiments were conducted over a three-year period. The first experiment was initiated in the fall of 1981 at the Gordon's Ferry site; the second experiment began about a year later at the Whitney Island site. The experimental procedures and the results from monitoring surveys at these first two sites through June 1983 are discussed in ANL/EES-TM-270, Vol. 1.<sup>1</sup> The experiments at the Savanna Bay and Duck Creek sites were initiated in the fall of 1983, and monitoring was continued for about a year. The complete results from these two sites are reported in ANL/EES-TM-270, Vol. 2.<sup>2</sup> Monitoring at the Gordon's Ferry and Whitney Island sites continued through the fall of 1984. In addition, 25 cores were taken in the bottom sediments at Gordon's Ferry during the summer of 1983 and analyzed for tagged sand. The results from these additional studies at the Gordon's Ferry and Whitney Island sites are the subject of this volume.

## 1.1 BACKGROUND

The Rock Island District has been investigating thalweg disposal as one option for disposing of uncontaminated sand dredged during maintenance of the nine-foot navigation channel in the Upper Mississippi River.<sup>3</sup> Thalweg disposal involves dredging sand from the shallow or shoal areas of the channel and disposing of it in deep water at another location along the channel.<sup>4</sup> Other disposal options include creating or nourishing beaches at the shoreline, piling sand on river islands, and placing sand in upland locations out of the floodplain.<sup>5,6</sup> The potential loss of aquatic and terrestrial habitats is an environmental concern common to all of the above options. Thalweg disposal has appeared attractive to the District in some instances because habitat disruption may prove to be small.

Because the dredged sand is introduced back into the river in deep areas of the main channel, sensitive habitat regions, such as main-channel border areas, sloughs, and shallow backwaters, are not modified immediately upon disposal. However, the potential for subsequent movement of the dredged sand out of the main channel into sensitive habitats remains a concern. In addition, the main-channel habitats themselves may be affected, depending on the length of time the dredged sand remains as a pile in the thalweg.

An experimental procedure was developed by Argonne and the Rock Island District to tag dredged sand with sand coated with fluorescent dye and to track the tagged dredged sand in the surficial bottom sediments after disposal in the thalweg. After several small-scale tests, the procedure was implemented in October 1981 at the Gordon's Ferry site, about 23 km (14.3 mi) south of Dubuque, Iowa, as part of routine channel dredging. Experience gained at this site was used to refine the experimental procedure and to demonstrate the usefulness of the technique. A second experimental site with different characteristics was established in September 1982 at Whitney Island near Hannibal, Missouri. The purpose of the experiments at the first two sites was to demonstrate the value of the tagging and tracking technique and to gain some understanding of the behavior of dredged sand after its disposal as a pile in the thalweg.

In October 1984, two other experimental sites were established near Savanna, Illinois -- the Savanna Bay site, where dyed sand was used to tag dredged sand, and a nearby site, Duck Creek, where bathymetric measurements alone were used to monitor

changes in the physical structure of the disposal pile. The experiments at the second two sites were conducted in support of fisheries studies being carried out by the U.S. Fish and Wildlife Service (USFWS) for the District to investigate the effects of thalweg disposal on fish populations. These two sites had different topographic and hydraulic characteristics than either of the first two sites.

Briefly, the disposal pile at the Savanna Bay site was placed in a deep, narrow channel of the river just upstream of a deep (>12 m [>40 ft]) hole, where the cross section of the river was quite restricted. At the disposal location near Duck Creek, the thalweg was wide and flat with a rocky bottom. This second location was to provide a site for USFWS to conduct fish population studies around artificial piles created in a normally flat environment. Argonne's role at this site was to provide the physical data on the locations and sizes of the piles needed to interpret the results of the fisheries studies.

The general pattern of behavior of the dredged sand after disposal was the same at all sites. Little downstream movement was detected until periods of high river discharge (flooding) occurred. At the time of these large discharges, the dredged sand was apparently mobilized along with other bed material and moved downstream in the main channel. The bathymetric identity of the disposal piles disappeared after such major discharge events, and the tagged dredged sand was apparently incorporated into bedforms in the main channel.

No evidence was found of coherent movement of dredged sand directly into sensitive areas such as main-channel borders, backwaters, or sloughs. In fact, little evidence was found of dredged sand being transported out of the main channel, as only a few grains of dyed sand were found in nearby border areas and sloughs.

## 1.2 OBJECTIVES AND SCOPE OF THE EXPERIMENTS

At the three major experimental sites, Gordon's Ferry, Whitney Island, and Savanna Bay, the overriding objective of the experiments was to determine the location of the dredged sand in the river following thalweg disposal. The objective at the Duck Creek site was to provide support for fish population studies around disposal piles in the thalweg in a region that was normally fairly flat. Argonne simply provided the physical data on the locations and sizes of the piles needed to interpret the results of the fisheries studies conducted by USFWS.

To determine the location of the dredged sand in the river following thalweg disposal, the dredged sand was tagged with dyed sand of similar size and shape during dredging, and surface bottom sediments were sampled to detect the dyed sand. The presence of dyed sand in the bottom sediments was considered an indication of the presence of dredged material. Sampling in sensitive habitat areas (e.g., main-channel borders, sloughs, and backwaters) had priority throughout the study. Sampling immediately after disposal focused on the disposal area and downstream areas, including sensitive regions. Because sampling was limited to surface bottom sediments at specific locations within the river, a mass balance for dyed sand was neither planned nor attempted.



Bottom cores were taken at the Gordon's Ferry site to obtain information on the three-dimensional distribution of the tagged dredged sand. Approximately two years after disposal, 25 bottom cores were collected in the original disposal area and downstream. Bathymetry was also measured at each coring location to establish the position of the core relative to local bottom structures.

During the early stages of the experiment at the Gordon's Ferry site, observations of dyed sand in the samples were reported in qualitative terms like "dyed sand present" and "no dyed sand present." A measure of the amount of dyed sand in samples was instituted shortly thereafter as a means of reporting the relative quantities of dyed sand. However, such quantitative statements do not imply a mass balance or concentration in the strict senses of those terms.

When it became apparent that the dredged sand had not dispersed widely within a few days of disposal, greater emphasis was placed on delineating the disposal pile and measuring its subsequent modification. Interest in the behavior of the disposal pile required sampling at higher spatial resolution in the vicinity of the disposal area. Ecological concerns related to the residence time of dredged sand at the disposal site helped to drive this interest. In this way, dual measurement objectives were established: sensitive habitats away from the disposal site were monitored to determine whether dredged sand had reached them, and the disposal site itself was surveyed to determine changes in the original placement configuration.

### 1.3 EXPERIMENTAL APPROACH

Based on its routine channel maintenance program and the suitability of certain sites for thalweg disposal, the Rock Island District, in consultation with Argonne, selected the sites for the thalweg disposal experiments. Site suitability was governed primarily by the availability of a section of deep channel for disposal within a reasonable downstream distance of the dredging location and by proximity to side channels or backwaters.

To estimate dyed sand requirements and to select an appropriate disposal location, the District estimated the size (volume) of the dredging cut on the basis of channel surveys made prior to dredging. However, the District also made detailed bathymetric surveys of the dredging and disposal areas immediately before the actual dredging began, and conditions encountered during dredging influenced the dredge cut. The need to modify earlier estimates of dredging volumes and specific locations was significant in the Gordon's Ferry and Whitney Island experiments. Consequently, dyed sand injection rates were determined just prior to initiation of dredging and were then adjusted to accommodate changes in dredging conditions.

Prior to dredging, Argonne used Corps of Engineers survey data and field markers to establish a coordinate system for the experiment. The coordinate system was checked in the field for consistency and applicability for future sampling and navigation. Argonne also measured the predredging bathymetry in the estimated disposal area and sampled surficial bottom sediments to confirm the absence of dyed sand. The Rock Island District prepared the dyed sand and delivered it to the dredge.

The hydraulically dredged sand was discharged directly through a downstream discharge pipeline or indirectly through a separate booster pump and discharge system. A disposal pile was created as the discharge pipeline moved upstream. During dredging, Argonne directed and monitored the injection of dyed sand into the suction side of the hydraulic dredge pump. The location of the end of the discharge pipe was recorded at regular intervals throughout the dredging operation. During the disposal operations at the Whitney Island and Savanna Bay sites, bathymetry was measured in the disposal area to assist in the placement of the dredged sand.

Shortly after dredging was completed, Argonne surveyed the disposal site and downstream areas. Bathymetry was measured in the disposal area to determine the size of the disposal pile. Sampling of surface bottom sediments at the disposal site and along downstream transects was accompanied by onboard observation of the samples to detect dyed sand grains. Stations in slough and backwater areas were also sampled. Sampling continued downstream from the disposal pile until transects were found from which samples showed no visual evidence of dyed sand. Subsequent surveys at the experimental sites were undertaken to gather information on the changes in the bathymetry of the pile and in the distribution of dyed sand in the surficial sediments. Navigation and plotting systems on the survey vessel permitted locating and returning to sample stations, with a resolution of a few meters.

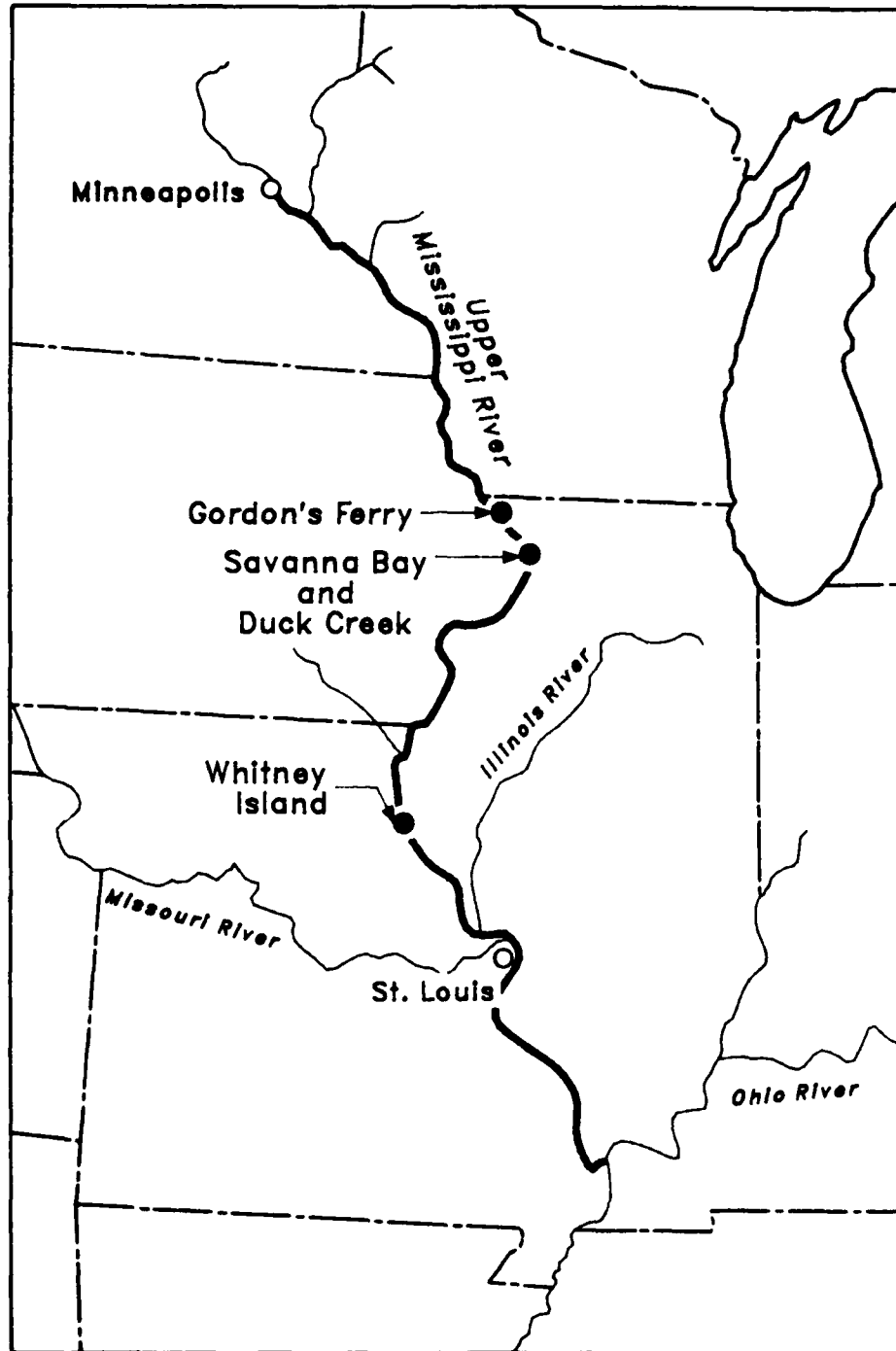
#### **1.4 EXPERIMENTAL SITES**

Figure 1 is a generalized map of the Upper Mississippi River, which shows the locations of all the experimental sites.

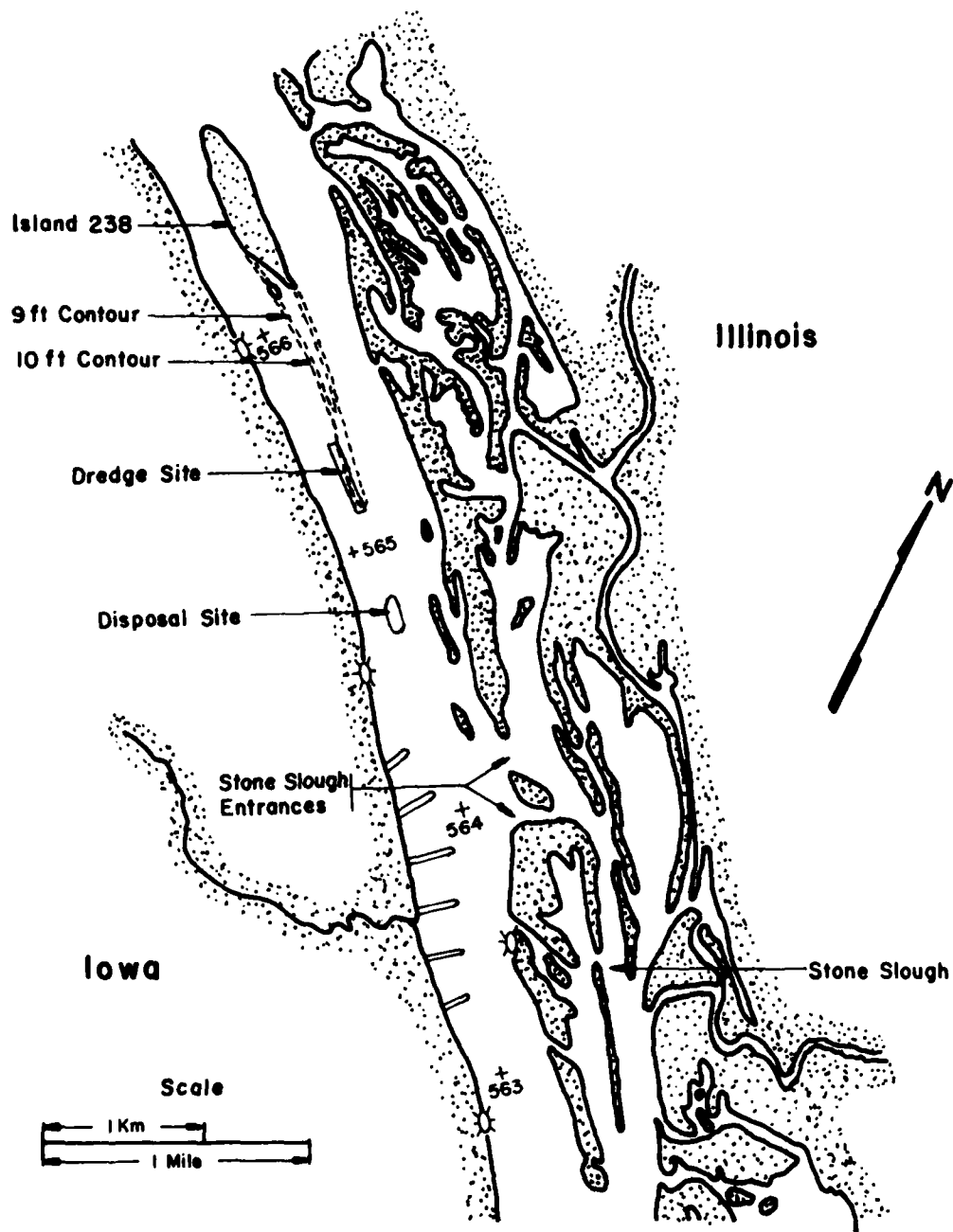
##### **1.4.1 Gordon's Ferry Site**

The Gordon's Ferry site is in Pool 12 about 12 km (7.7 mi) upstream from Lock and Dam 12 at Bellevue, Iowa, and about 23 km (14.3 mi) downstream from Dubuque, Iowa. As indicated in Fig. 2, the area dredged in October 1981 extended from about river mile 565.2 to mile 565.5 (measured from the confluence with the Ohio River), and the disposal area from about mile 564.6 to mile 564.9.

The reach in which the experiment was conducted is relatively straight, varying in width from 400 m (1300 ft) to 600 m (2000 ft). The Iowa bank is steep and rises abruptly in a railroad embankment revetted with rock. Downstream from the disposal area are six submerged wing dams along the Iowa shore. The Illinois side of the river is marked by lowlands cut through with sloughs and backwaters for at least 0.8 km (0.5 mi) inland. The normal river channel is well defined by the river sides of islands. Three small islands are located in the channel near the Illinois bank; downstream from the disposal area are two openings into Stone Slough. The navigation channel is on the Iowa side of the river in this reach. The bottom sediments are clean sands that generally range in size from fine to coarse. Gravel has occasionally been found in bottom samples, and mud occurs in the backwaters and sloughs. The bottom conditions found in the main channel of this reach include both flat-bed and dune regimes.



**FIGURE 1** Location of Experimental Sites along the Upper Mississippi River



**FIGURE 2** Gordon's Ferry Experimental Site in Pool 12 of the Upper Mississippi River

Dredging at Gordon's Ferry was necessitated by a longitudinal sand bar formed as a downstream, underwater extension of Island 238. Predredging bathymetric measurements by the Rock Island District on October 15, 1981, indicated that the shoal region of 2.7-m (9-ft) or less depth\* was about 100 m (330 ft) wide and extended downstream about 975 m (3200 ft) from the island. The shoal region of 3-m (10-ft) depth extended downstream about 360 m (1180 ft) farther and shifted from a center channel location upstream to the one-third channel location on the Iowa side, encroaching on the navigation channel area.

The channels on either side of the island and shoal region were at least 3.7 m (12 ft) deep and reached depths of 6.1 m (20 ft) on the Illinois side. At one time, the navigation channel was located on the Illinois side of the island. Almost immediately downstream of the shoal region, a depression 120-150 m (390-490 ft) wide and about 700 m (2300 ft) long in the center of the channel reached depths of 8.5 m (28 ft). The portion of this depression that was farthest upstream provided the location for disposal of the dredged sand. At the time of disposal, the bottom material in this depression was primarily fine sand.

Water depths downstream of the disposal site were generally greater than 4.3 m (14 ft) across the entire channel, decreasing abruptly at the banks and near islands on the Illinois side. The region of primary concern with regard to the modification of habitats due to transport of sand from the disposal area was Stone Slough. The two principal entrances to Stone Slough occur about 1 km (0.6 mi) downstream from the disposal area. They have narrow, but deep, channels into the slough and connect with a channel through the slough that parallels the main channel. At the upstream end, the channel in the slough is only about 3-6 m (10-20 ft) wide and is surrounded by shallows generally less than 1 m (3 ft) deep. The channel widens in the downstream direction. The bottom in the shallows is mud, while the bottom in the deep channel is sand. The presence of the sand bottom and general observations by District personnel suggest that the flow through Stone Slough is significant during high water conditions. Thus, the possibility of transport of sand from the disposal area into Stone Slough after disposal had to be addressed in the experiment.

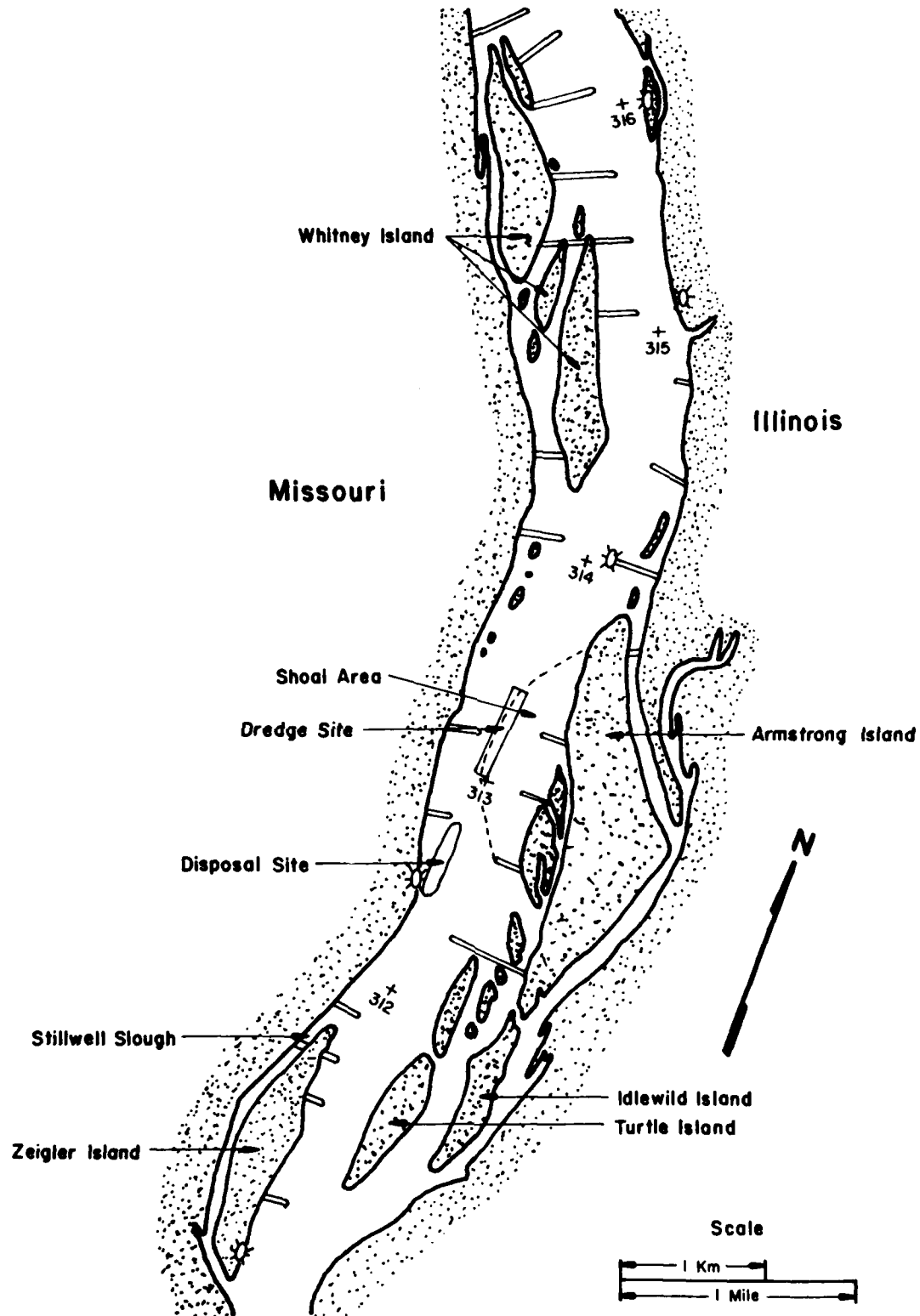
#### 1.4.2 Whitney Island Site

The Whitney Island site is in Pool 22 about 19 km (12 mi) upstream from Lock and Dam 22 and about 6 km (4 mi) upstream from Hannibal, Missouri. The site is about 2 km (1.2 mi) downstream from Whitney Island. As indicated in Fig. 3, the area dredged in September 1982 extended from about river mile 313.0 to mile 313.4, and the disposal area extended from about mile 312.3 to mile 312.8.

In contrast to the Gordon's Ferry site, the reach for the Whitney Island experiment is not straight and has more complex geometry. The navigation channel or sailing line follows the outside (Illinois side) of the bend around Whitney Island, crosses the river off Armstrong Island, hugs the bank on the Missouri side, and passes between

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\*In Sec. 1.4, all depths are relative to flat-pool elevation.



**FIGURE 3 Whitney Island Experimental Site in Pool 22 of the Upper Mississippi River**

Zeigler Island and Turtle Island before bending toward the city of Hannibal. The river channel width varies from 400 m (1300 ft) to 730 m (2400 ft) in the reach, and submerged wing dams protrude from the banks on both the Missouri and Illinois sides. In the portion of the reach involved in the experiment (dredging and disposal areas), the deep water is predominately along the Missouri shore, and depths decrease gradually from the nine-foot navigation depth within about 150 m (490 ft) of the Illinois bank. Revetment protects the Missouri bank near the disposal site. The bottom sediments are clean sands that generally range from medium to coarse, although some fine sands are present. Large sand dunes often occur along the bottom in the vicinity of the disposal area.

Shoaling from the Illinois bank outward just above river mile 313 was detected in an August 18, 1982, bathymetric survey by the Corps. This region of channel crossing between wing dams had shoaled such that the opening between the bar on the Illinois shore and the wing dam from the Missouri shore was reduced to about 120 m (390 ft). The bar continued down the Illinois side of the river along Armstrong Island and offshore about the length of the wing dams. Only that portion of the bar constricting the opening between wing dams was dredged. Downstream of river mile 313 on the Missouri side of the river, a hole 6.1 m (20 ft) or more deep and about 200 m (650 ft) wide extended for about 0.8 km (0.5 mi). This depression, which was next to the bank and along the edge of the navigation channel, was chosen for the disposal area.

About 0.8 km (0.5 mi) downstream from the disposal area, Stillwell Slough, behind Zeigler Island, has its upstream entrance. Although a submerged wing dam is positioned across the entrance and the navigation channel bends away from the slough, it was obvious that the backwater area might be affected by the disposal activity.

## 1.5 SCOPE OF THIS REPORT

The specific details of the experimental procedures and methods employed, with the exception of the bottom coring, are reported in ANL/EES-TM-270, Vol. 1<sup>1</sup> and are only briefly reviewed in Sec. 2 of this volume. However, the coring operation and associated data-reduction procedures are described in detail in Sec. 2.

The field experiment at the Gordon's Ferry site is briefly summarized in Sec. 3, as Volume 1<sup>1</sup> covers the details of the dredging and tagging operation and presents the results from the first seven surveys. However, the results of the additional two surveys and the coring experiment at the Gordon's Ferry site are presented in Sec. 3.

Section 4 summarizes the dredging and tagging operation at the Whitney Island site and the results from the first five surveys but does discuss the additional two surveys in detail. Section 5 relates the main results from the Gordon's Ferry and Whitney Island sites and draws general conclusions from the results at all of the experimental sites.

## 2 EXPERIMENTAL PROCEDURES

Sections 2.1-2.3 review the dredging and tagging operations, survey protocols, and data-reduction procedures that are described in detail in ANL/EES-TM-169<sup>7</sup> and ANL/EES-TM-270, Vol. 1.<sup>1</sup> Procedures for the coring operation conducted at the Gordon's Ferry site and the data-reduction techniques used to analyze the resulting bottom cores are covered thoroughly in Secs. 2.4 and 2.5. Section 2.6 briefly discusses bench experiments to determine the durability of the fluorescent dye on sand grains.

### 2.1 DREDGING AND TAGGING OPERATION

The sand to be dyed was selected to match as closely as practical the grain-size distribution of the sand to be dredged. After the sand was dyed by the Corps of Engineers with Day-Glo Rocket Red (AX13)<sup>TM</sup>, it was packaged in bags containing about 36 kg (80 lb) each and loaded onto a barge for transportation to the experimental site.

The dredging was done by the Corps of Engineers' dredge *William A. Thompson*,<sup>3</sup> which is a hydraulic cutterhead dredge with a nominal maximum capacity of 19,000 m<sup>3</sup> (25,000 yd<sup>3</sup>) of material per day. The dyed sand was injected as a slurry into the dredge pipeline just ahead of the main pump. The dredged-sand/dyed-sand mixture was carried from the dredge to the disposal site through a 0.5-m- (20-in.-) diameter floating pipeline. The dredged material then spilled out from the discharge end of the pipeline, which was located above the water surface.

### 2.2 SURVEY PROCEDURES

The disposal area and downstream areas were surveyed to determine the location of the tagged disposal material and changes in river bottom bathymetry. A 7.6-m (25-ft) Monark aluminum work boat was used for all surveys. A Motorola Mini-Ranger<sup>TM</sup> system was interfaced with a Hewlett-Packard programmable calculator, and an x-y flatbed plotter was used for real-time boat positioning. Typically, the position of the boat could be determined to within a few meters. A rectangular coordinate system was established at each experimental site. Shorelines and other features were digitized in terms of this coordinate system using charts supplied by the District. Plotter charts that included sampling locations, shorelines, and other features of interest were prepared for the onboard x-y plotter in advance of each survey.

Bathymetry was measured with a Raytheon recording depth sounder by driving the boat at a constant speed along preestablished straight-line transects. Marks were placed on the depth-sounder record corresponding to transect end points on the x-y plotter charts. The depth-sounder record was then interpolated between those end points. The boat usually stayed within 5-10 m (15-30 ft) of the established transect, but deviations of as much as 20 m (65 ft) did occasionally occur due to changing currents or winds.



During each survey, bottom samples were collected in the disposal area and downstream. Samples were immediately analyzed to determine whether tagged dredged sand was present. A grid of sampling locations was established on the plotter chart of the positioning system prior to each sampling survey. In general, the sampling locations were more closely spaced in the immediate vicinity of the disposal site to resolve the configuration of the disposal pile and reveal any changes that may have occurred since the previous survey. The sampling locations were more widely spaced downstream and included border areas and sloughs as well as the main channel. This spacing permitted investigating the general areas into which the tagged dredged sand might have migrated. As the survey progressed, sampling locations were added or deleted from the grid. Such adjustments increased the resolution in regions of interest and allowed coverage of additional areas into which tagged material might have migrated.

The boat was driven to the sampling location, and the surficial bottom sediments were sampled using a Ponar Grab Sampler<sup>™</sup>. A portion of the sample was spread onto a 23 × 23 cm (9.1 × 9.1 in.) tray for visual inspection and photographing while illuminated by ultraviolet light. Several exposures with different exposure times were taken of each sample. In addition, the classification of the bottom material by grain size was visually estimated. Finally, each sample was placed in a labeled polyethylene container and saved in case additional analysis might be required.

Estimating the amount of dyed sand in each bottom sample as it was collected permitted subsequent sampling locations to be adjusted to better delineate the extent of the tagged sand. However, small dyed sand grains that were later visible in the photographs were not always visible during the onboard examination.

### 2.3 DATA REDUCTION

After each field survey, positioning-system plotter charts, depth-sounder strip charts, exposed photographic film, bottom samples, and other data records were returned to Argonne for processing. Data were extracted from these records and stored in a format convenient for tabular and graphic presentation by the Argonne computer.

Water depth information from the depth-sounder strip charts was digitized, and the data were stored in the Argonne computer. By interpolating the digitized data between the transect end points and correcting for changes in water level, bottom profiles could be plotted by the computer. Even though the attempt was made to follow the same transects on subsequent bathymetric surveys, the boat did deviate in varying degrees from the prescribed paths. Therefore, only general trends in changes in topographic features should be considered significant. Individual transects from successive surveys should not be compared in detail.

The bottom samples were stored in case further analysis might be required, particularly with regard to photographic records. The photographic film was developed and processed into slides, which were labeled and stored in standard Kodak Carousel<sup>™</sup> slide trays. Each series of slides (various exposure times) corresponding to individual bottom samples was examined, and the number of dyed sand grains visible on the surface of the sample tray was determined by direct count or, if the number was very large

(>200), by estimation. The coordinates of the sampling locations were extracted from the positioning-system plotter charts, and all information was stored in the Argonne computer. The data record for each sample includes:

- Collection date,
- Collection time,
- Sample identification number,
- Sampling location (x-y coordinates),
- Approximate water depth at sampling location,
- Number of dyed sand grains visible in the photographic slides of the sample tray,
- Classification of the sample by approximate grain size, and
- Identification number for the photographic slides.

Computer programs were used to present several of these parameters in various graphical formats.

## 2.4 CORING OPERATIONS

### 2.4.1 Pneumatic Coring Device and Platform

A lightweight pneumatic coring device (vibracorer), designed and built by the Coastal Engineering Research Center (CERC),<sup>8</sup> was borrowed from CERC for coring at the Gordon's Ferry site. Figure 4 is a picture of the coring device on the support barge. The coring device consists of three major parts: frame, vibrator, and core tube. The frame was constructed of aluminum structural members and steel cables, and was about 3 m (10 ft) in height, with a square base about 1.2 m (4 ft) on a side. The 33-kg (72-lb) vibrator was a piston-type (7.6-cm [3-in.]) industrial vibrator (Model BH3 Long-Stroke, Impacting) manufactured by the National Air Vibrator Company, Houston, Texas. The

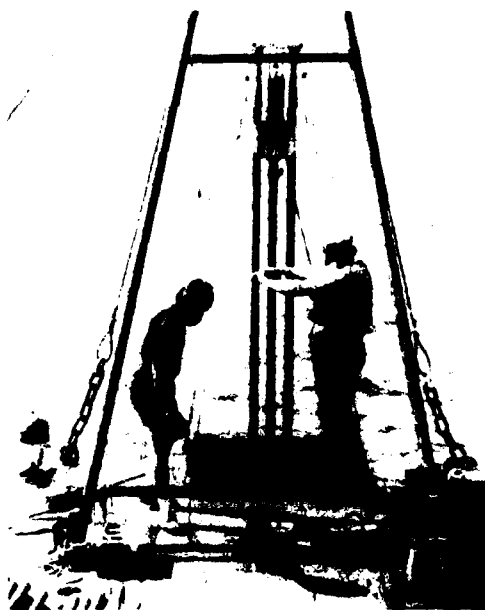


FIGURE 4 Lightweight Pneumatic Coring Device

vibrator is visible in Fig. 4 just beneath the cross member of the A-frame. The vibrator was mounted on a sliding bracket supported by the two vertical outer pipes in the center of the frame, allowing the vibrator to slide up and down the two pipes. The 2.1-m- (7-ft-) long core tube (center pipe in Fig. 4) was Schedule 120 (thick wall), nominal 5.1-cm (2-in.) polyvinyl chloride pipe. The core tube was threaded on one end and screwed directly into the base of the sliding bracket. The core tube is being tightened with a large pipe wrench in the figure. The other end of the core tube had six small threaded holes to attach the aluminum cutterhead and stainless steel core catcher. Figure 5 shows a core tube with cutterhead and core catcher attached and a disassembled cutterhead and core catcher.



**FIGURE 5 2.1-m Polyvinyl Chloride Core Tube, Cutterhead, and Core Catcher Used with the Vibracorer**

The platform used for the coring operation was a Corps 12.2-m (40-ft) pontoon barge modified by the Rock Island District by attaching an A-frame crane near the bow of the barge. The coring device was lowered and retrieved using the A-frame and a 12 V dc electric winch mounted behind the A-frame. The winch was powered by a storage battery, which was periodically charged with a portable gas-driven 120 V ac generator and battery charger.

The vibrator was activated, through flexible air hoses, by a portable, gas-driven air compressor on board the barge. Figure 6 shows the barge, pusher boat, A-frame, winch system, and compressor.

#### **2.4.2 Core Collection Procedures**

The vibracorer was positioned on the river bottom in the following manner. The Argonne survey boat was driven to the location to be cored using the high-resolution position-plotting system. When the boat was at the coring location, the depth was recorded and a buoy was attached to an anchor with a line whose length was only about a foot longer than the depth. With the boat pilot maintaining the position as close as possible to the desired coring location, the buoy was dropped overboard from a position in the stern of the boat immediately below the receiver/transmitter for the positioning system. The survey boat then moved away and returned to the buoy to check its position. If the position of the buoy was not within a few feet of the desired location, the buoy was dragged into position.



**FIGURE 6 12.2-m Pontoon Barge Used for the Coring Operation**

Once the buoy was in place, the pontoon barge with the vibracorer was moved to a location directly upstream of the buoy and heading in an upstream direction. Two anchors were deployed off the bow at about  $45^\circ$  angles on either side of the centerline of the barge. The barge was then allowed to drift with the current until the bow was near the buoy. By adjusting the anchor lines, the center of the bow could be positioned to within a few feet of the buoy. Although it would have been possible to position the bow almost exactly at the buoy by adjusting the anchor lines, some space was required to prevent the buoy line and the coring device from tangling. This small deviation was estimated and accounted for when recording the location of the core. The river current was usually sufficient to keep the anchor lines taut. On those occasions when the wind was from the stern, a third anchor was required.

Core tubes were prepared by securing the cutterhead and core catcher to the penetration end of the core tube with stainless steel machine screws, using the six threaded holes. The threaded end of the core tube was greased and screwed into the sliding bracket of the coring device, using a large pipe wrench to secure the tube tightly.

With the barge in position, the coring device was lifted off the deck, and the vibrator was activated while the device was out of the water. The coring device was then lowered to the river bottom, and the support cable was allowed to go slack. The time was noted, and the cable was marked with tape to provide a reference point for monitoring the progress of the core tube as it penetrated the bottom sediments.

Generally, about 15-30 min were required before the core tube reached maximum penetration or intercepted an impenetrable layer within the sediments. The lengths of the bottom cores were 1.1-2.1 m (3.6-6.9 ft). When penetration had ceased, the winch was used to extract the core tube from the bottom and to lift the coring device out of the water. Vibration was continued until the device was out of the water to aid in extracting the core from the bottom and to ensure that no water entered the vibrator through the air-release nozzle.

When the coring device was back on the barge, the core tube was unscrewed from the sliding bracket. Any water in the top of the core tube was carefully poured off, and any tubing above the sediment core was cut off. A rag was packed into the top of the tube, and the end was sealed with plastic electrical tape. The core tube was then turned horizontal, and the cutterhead and core catcher were removed. Finally, the penetration end of the tube was also packed with a rag and sealed with tape. The packed and sealed core tubes were transported back to Argonne in a near-vertical position to reduce the chance of disturbing the sediment cores.

#### **2.4.3 Bathymetric Measurements in Support of Coring**

The location of each core with respect to the local dune structure on the river bottom was determined by bathymetric measurements at each coring location. The method used to collect the bathymetric data was similar to the one used for the other surveys. A longitudinal (along-river) bathymetric transect that passed directly through the location to be cored was drawn on the plotter chart of the onboard positioning system. The boat was then driven at a constant speed along that transect, with the recording depth sounder operating. The end points of the transect and the coring location were marked on the depth-sounder record. Great care was taken to ensure that the boat did not deviate from the preselected course and that it passed as close as possible to the coring location. Several attempts were sometimes necessary to ensure that the desired accuracy in position was achieved. The depth-sounder records were digitized, and the data were stored in the Argonne computer in the same manner as the other bathymetric data.

### **2.5 CORE-OPENING AND ANALYSIS PROCEDURES**

#### **2.5.1 Core-Opening Procedures**

To open the core tubes without significantly disturbing the sediment cores, a longitudinal section of the tube wall was removed. A jig with clamps to hold the tube and a guide rail for a saw was built from aluminum channel stock. The core tube was clamped in the jig, and a standard hand-held circular saw was used to make a cut just through the tube wall along the length of the tube, leaving about 3 cm (1 in.) uncut at each end. The core tube was turned about 120° and reclamped, and a second longitudinal cut was made, again leaving about 3 cm (1 in.) uncut at each end. Figure 7 shows a core tube being opened in the manner described.

After both longitudinal cuts had been made, a handsaw was used to make a lateral cut a few centimeters from each end and between the two longitudinal cuts. These four saw cuts, two longitudinal and two lateral, completely severed a section of the tube wall that ran the length of the tube, except for the 3-cm (1-in.) sections at each end. The severed section of wall was removed to expose about a 120° sector of the sediment core for its entire length. Figure 8 shows an exposed core.

### 2.5.2 Analysis of Core Material for Dyed Sand

As soon as each core was opened, it was visually inspected to see whether vertical stratification was evident. Although some stratification was observed, the outer surface of the core generally contained material that was finer than that in the interior. Apparently, the vibrations that drove the core tube into the river bottom caused finer material to migrate to the outer surface of the core. A section judged to consist of fine or medium sand based on the outer surface of the core was often found to contain gravel in the center. The exposed outer surface of the core was also inspected under a portable ultraviolet light to see whether dyed sand was present.

The sediments in each core tube were removed in 10-cm (3.9-in.) segments (see Fig. 9). First, the tube was marked at these intervals, starting from the top of the core, which corresponded to the interface between the water and sediment. The sediment in each interval was then carefully removed, starting from the bottom of the core tube. This approach reduced the chances of the deeper samples being contaminated by material higher up in the core, which was more likely to contain dyed sand.

The material from each segment was then spread on a 23 × 23 cm (9.1 × 9.1 in.) tray and inspected and photographed under ultraviolet light in the same manner as the surficial bottom samples collected in the field. The segment length was chosen so that the volume of material was approximately equal to the volume of each surficial bottom sample. Consequently, the results of analyzing the photographs for dyed-sand content are expected to be comparable for the two very different methods of sampling.

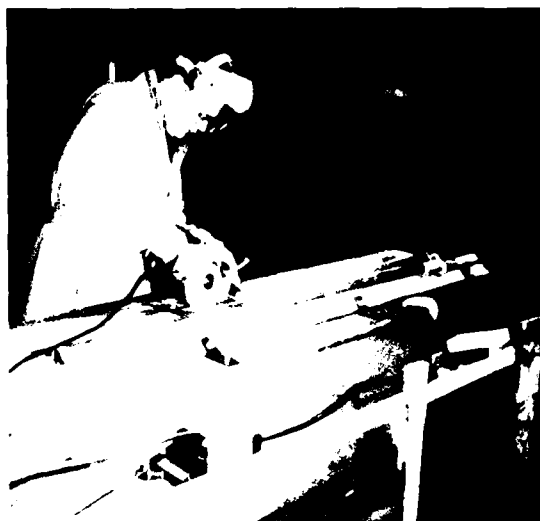


FIGURE 7 Core Tube Being Opened Using the Circular Saw and Jig

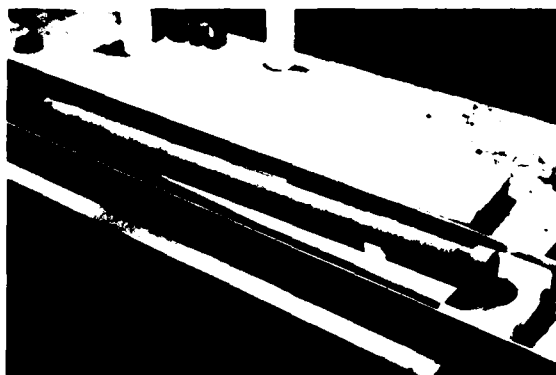


FIGURE 8 Opened Core Showing the Exposed Bottom Material

After each core segment was removed from the core tube and spread on the sample tray, it was handled in exactly the same manner as the surficial bottom samples (see Ref. 1). The samples were photographed under ultraviolet light using three different exposure times (2 s, 7 s, and 12 s) and then saved in labeled polyethylene containers in case additional analysis might be necessary. The photographic film was processed into slides, and the slides were examined to determine the number of dyed sand grains visible on the surface of the sample tray. Finally, results were stored in the Argonne computer for analysis and graphical presentation.



**FIGURE 9 Removal of Sediments from a Core in 10-cm Segments**

## **2.6 DURABILITY OF DYE ON SAND GRAINS**

During the planning and execution of these experiments, the issue arose of how well the dye adheres to individual sand grains in the river-bottom environment. Therefore, simple bench-type experiments were conducted to address this issue in a purely qualitative manner. A hobby-grade lapidary tumbler was used to tumble dyed sand grains for long periods of time in an attempt to simulate the wear that dyed-sand grains might be subjected to in the river environment.

The relationship between time in a tumbler and distance traveled downstream is at best uncertain. Moreover, the wearing down of individual particles by abrasion and related processes is a function of several variables, including the size of the particles; the durability of the material; the nature and violence of the action; the size and proportions of associated materials; and the duration of the abrasive action, which is related to the distances traveled.<sup>9</sup>

Strict treatment of the effects of abrasive processes on dye-covered sand particles is beyond the scope of this study. Rather, the objective of these experiments was to estimate the durability of the dye coating on the basis of the length of time required in a tumbler to remove the dye from a sand grain. Even after 400 hr of tumbling, sufficient dye remained on the particles to make them readily apparent under ultraviolet light.

Initially, a few relatively large dyed sand grains ( $\approx 3$  mm) were tumbled in a mixture of fine sand and water and periodically inspected for wear. The large grains were used in the initial experiments because of the difficulty of finding small dyed sand grains in the large amount of sand required for the tumbler. Removal of dye from the dyed grains could not be discerned until after about 100 hr of tumbling. Inspection of one of the grains under a low-power microscope (20x) at that time indicated that some of the dye was wearing from the points and edges of the dyed grain. After about 170 hr of

tumbling, that same dyed grain was judged to be about 50% bare, with the bare parts showing evidence of having been polished.

Continued tumbling appeared to have little effect on the remaining dye because it was protected in depressions and crevices; however, the bare portions of the grain became more rounded and polished. The tumbling of this grain was stopped after about 300 hr, with the grain still judged to be about 50% bare of dye. Other grains of approximately the same size were tumbled for as long as 400 hr; microscopic examination revealed that considerable dye remained on the grains in crevices and depressions. Despite the removal of some dye, all of the tumbled grains were readily visible under ultraviolet light.

A second experiment was conducted using small dyed sand grains that were more representative of the nominal size used for tagging the dredged material. As noted above, the problem with using small grains is that they are almost impossible to find among the undyed sand grains after tumbling. Therefore, only a very small amount of undyed sand was used in the tumbler. Although the dyed sand grains could then be found after tumbling, changes in the condition of their dye coatings were difficult to assess because individual grains could not be identified for before-and-after comparisons.

With a smaller amount of sand in the tumbler, abrasion may have been much more severe because the particles were in motion a much greater fraction of the time than if larger quantities of sand had been used. When the drum of the tumbler was about 25% full, which is the volume recommended for tumbling and the amount used for tumbling the large grains, an individual sand grain was imbedded in a clump of sand and thus immobilized for about 50% of each revolution. However, when only a little sand was in the drum, the grains were moving most of the time and thus impacting with and abrading against other grains for a greater portion of each revolution.

In the experiment with the small dyed sand grains, four grains were tumbled for about 26 hr, but only three grains could be found at the end of the tumbling period. Microscopic examination of the three grains revealed that about 80% of the dye coating had worn off two of the grains, with the remaining dye occurring mostly in crevices and depressions. In contrast, virtually no wear was evident on the third dyed sand grain. All three grains were readily visible under ultraviolet light. In fact, the different amounts of dye loss were not evident when the grains were viewed under the ultraviolet light.

Estimates of distances traveled in the tumbling mill based on the size of the drum, the speed of rotation, and the duration of the experiment varied from 15 to 30 km (10-20 mi) and from 100 to 200 km (60-120 mi) for the small and large grains, respectively. The smallest of these distances, 15 km (10 mi), is more than five times farther than any grain has been tracked at any of the three disposal sites. On the basis of these tests, it appears unlikely that any wear of the dye coating that has occurred in the river will have rendered the grains undetectable under ultraviolet light.

Two dyed sand grains that had traveled downstream in the river environment were also examined under the microscope. These grains were taken from two surficial bottom samples collected during the last survey at the Whitney Island site about two years after the original tagging operation. It was not possible to determine exactly how



far each grain had traveled because their locations at the time of disposal can only be estimated to within about 700 m (2300 ft). It is estimated that the first grain traveled about 900-1600 m (2950-5250 ft) and that the second grain traveled about 200-900 m (650-2950 ft). Microscopic examination of the first grain revealed little wear, and the grain was about 80% covered with dye. The second grain showed considerable wear and was only about 20% covered with dye. Both grains were readily visible under ultraviolet light.

In summary, although the evidence is circumstantial, it appears that the dye adheres to the sand grains in sufficient quantity and for a long enough time for the dyed sand to be easily identified under ultraviolet light for the times and distances involved in the field experiments.

### 3 FIELD EXPERIMENTS AND RESULTS AT GORDON'S FERRY

The field activities and the results from the first seven surveys at the Gordon's Ferry site, which are summarized here, are described in detail in ANL/EES-TM-270, Vol. 1.<sup>1</sup> Section 3.1 reviews the dredging, tagging, and disposal operation and summarizes the results from Surveys I-VII. Detailed results from the remaining two surveys and the coring operation are discussed in Secs. 3.2 and 3.3. All the results from the experiments at the Gordon's Ferry site are summarized in Sec. 3.4. Table 1 lists the important experimental activities conducted at the Gordon's Ferry site. Figure 10 is a plot of mean daily river discharge recorded by the Rock Island District at Lock and Dam 12, which is about 12 km\* downstream of the disposal area.

#### 3.1 REVIEW OF DREDGING, TAGGING, AND DISPOSAL OPERATIONS AND SUMMARY OF SURVEYS I-VII

The dyed sand used to tag the dredged sand was generally fine grained and chosen to match, as closely as logistically possible, the sand that was dredged. During the dredging operation, 11,400 kg of dyed sand was mixed with the dredged sand to yield an average concentration by weight of about 1000 ppm. Dredging took place on October 27 and 28, 1981, at the location indicated in Fig. 11. The tagged sand was deposited as a relatively straight pile in a depression along the river bottom that was initially about 8.0-8.5 m deep.

The first bathymetric survey, which took place immediately following the disposal operation, showed that the disposal pile was about 1.2-1.9 m high, about 300 m long, and about 25-45 m wide at the base. It was located in the vicinity of the thalweg of the river where the natural water depth was about 8.0-8.5 m. Figure 12 shows the results from this bathymetric survey in the form of a perspective plot, with the base of the plot taken arbitrarily at a depth of 10 m.

Figure 13 shows the bottom sampling locations for the first survey, the number of dyed sand grains observed on the surface of the sample tray at each location, the paths of the bathymetric transects, and the location of the peak and the lateral extent of the disposal pile as determined from the bathymetric survey. An area yielding samples with significant counts of dyed sand (>3) extended about 500 m downstream of where the physical pile appeared on the bathymetric transects.

The disposal pile remained a distinct bathymetric feature until the first period of high flow after disposal (see Fig. 10) in the spring of 1982. Bathymetric measurements made after this spring flood showed that sand dunes were present in the disposal area, probably indicating a return to the bottom forms existing prior to disposal. However, it was not until after a second spring flood a year later (Survey VII) that significant downstream movement of the tagged sand was observed. Figure 14 shows the distribution of tagged sand at the Gordon's Ferry site immediately after disposal (Survey I) and

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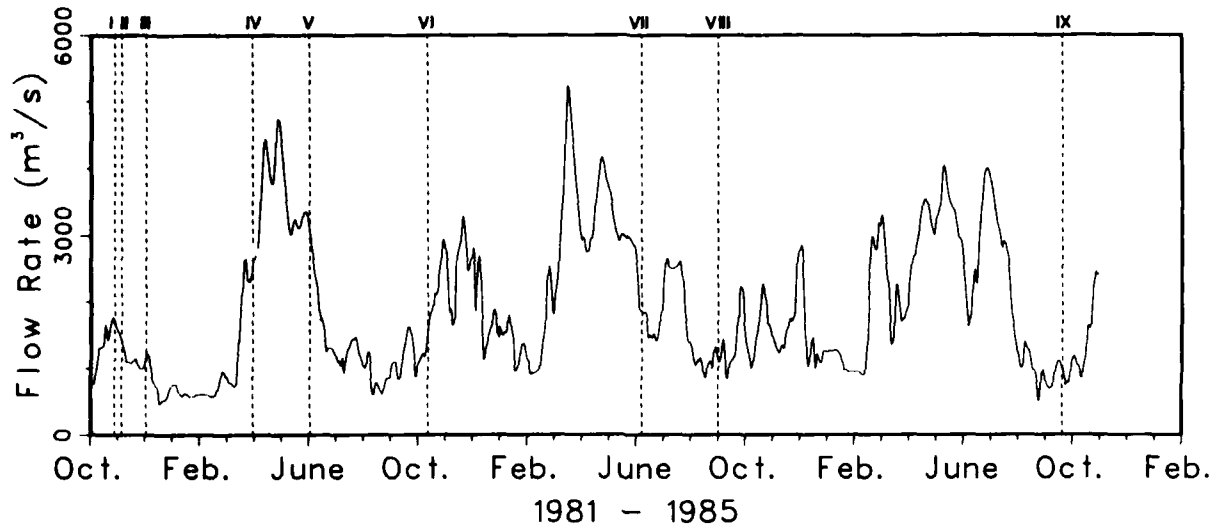
\*In Sec. 3 and the following sections of this report, conversions to English units will not be provided.

TABLE 1 Experimental Activities at the Gordon's Ferry Disposal Site

Experimental Activity	Date	Time after Disposal (days) <sup>a</sup>	Number of Bottom Samples Collected
Background bottom samples	October 26, 1981	-2	13
Predisposal bathymetry	October 26, 1981	-2	NA <sup>b</sup>
Dredging and disposal operations	October 27-28, 1981	0	NA
Survey I	October 28-30, 1981	0	86
Survey II	November 5-6, 1981	8	64
Survey III	December 2-3, 1981	35	56
Survey IV	March 30-April 1, 1982	153	49
Survey V	June 2-3, 1982	217	79
Survey VI	October 12-13, 1982	349	77
Survey VII	June 7-9, 1983	588	151
Survey VIII	August 23-24, 1983	665	75
Coring	August 24-31, 1983	666	NA
Survey IX	September 18-20, 1984	1057	225

<sup>a</sup>Time from the end of disposal operations on October 28, 1981.

<sup>b</sup>Not applicable.



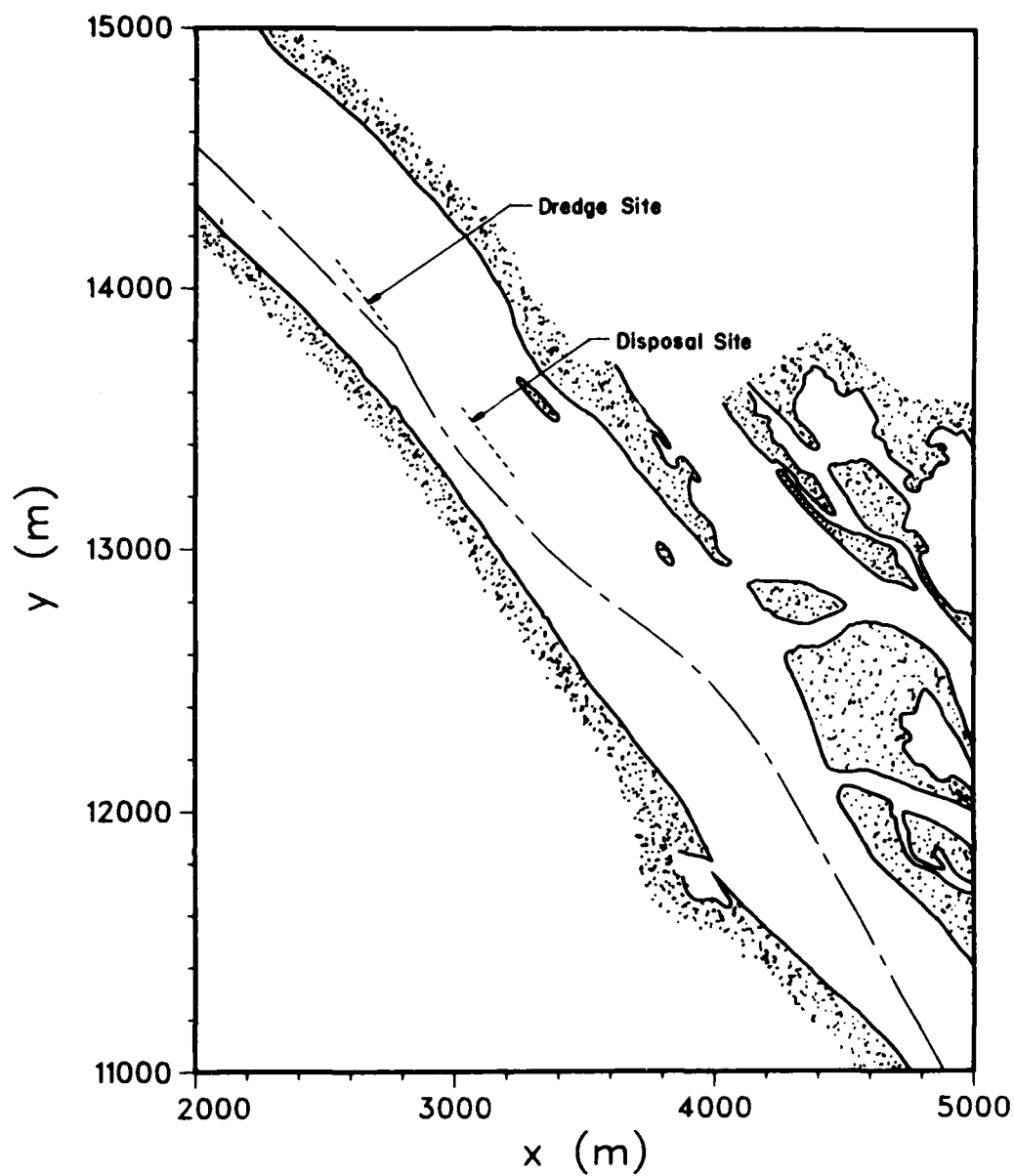
**FIGURE 10 Mean Daily River Discharge for the Gordon's Ferry Site as Recorded at Lock and Dam 12, with the Dates of the Surveys Indicated**

after the second spring flood (Survey VII). The contour chosen as delineating the extent of the tagged sand was the contour that enclosed all sampling locations where three or more dyed sand grains were found on the surface of the sample tray. This choice was based on statistical arguments discussed in ANL/EES-TM-270, Vol. 1.<sup>1</sup> Even after the second spring flood, during which tagged sand had moved downstream, no evidence was found of migration of tagged sand out of the thalweg into main-channel borders, backwaters, or sloughs.

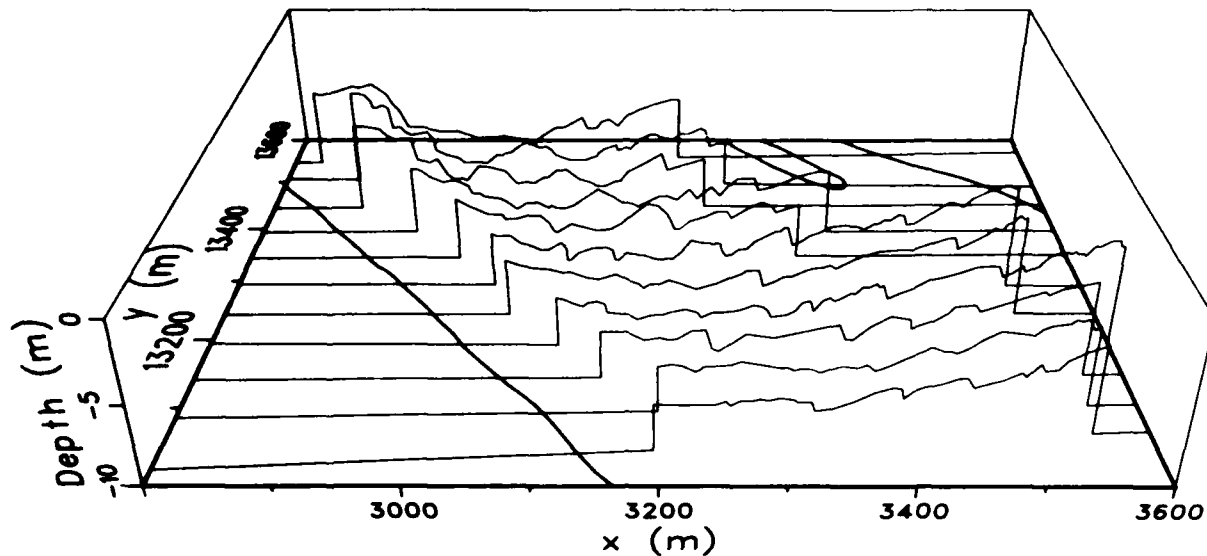
The bottom material in the disposal area was classified as fine sand prior to the disposal operation. After disposal, the bottom material gradually changed from fine sand on Survey I to coarser sand by Survey VII.

The results from the first seven surveys at the Gordon's Ferry site can be summarized as follows:

- No evidence was found of large-scale migration of dredged sand into biologically sensitive main-channel borders, backwaters, or sloughs.
- The physical disposal pile, which was originally quite distinct bathymetrically, lost its topographic signature after the first spring flood (Survey V) and eventually evolved into channel bedforms.
- The area of tagged sand, as defined by the three-dyed-sand-grain contour, showed little change until after the second spring flood (Survey VI) when it elongated by a factor of two, with a corresponding doubling in area.
- Bottom sediments in the original disposal area gradually changed from fine to coarse sand.



**FIGURE 11 Map of Gordon's Ferry Site Showing Dredging and Disposal Areas**



**FIGURE 12 Perspective Plot of Bathymetric Transects for Survey I at the Gordon's Ferry Disposal Site**

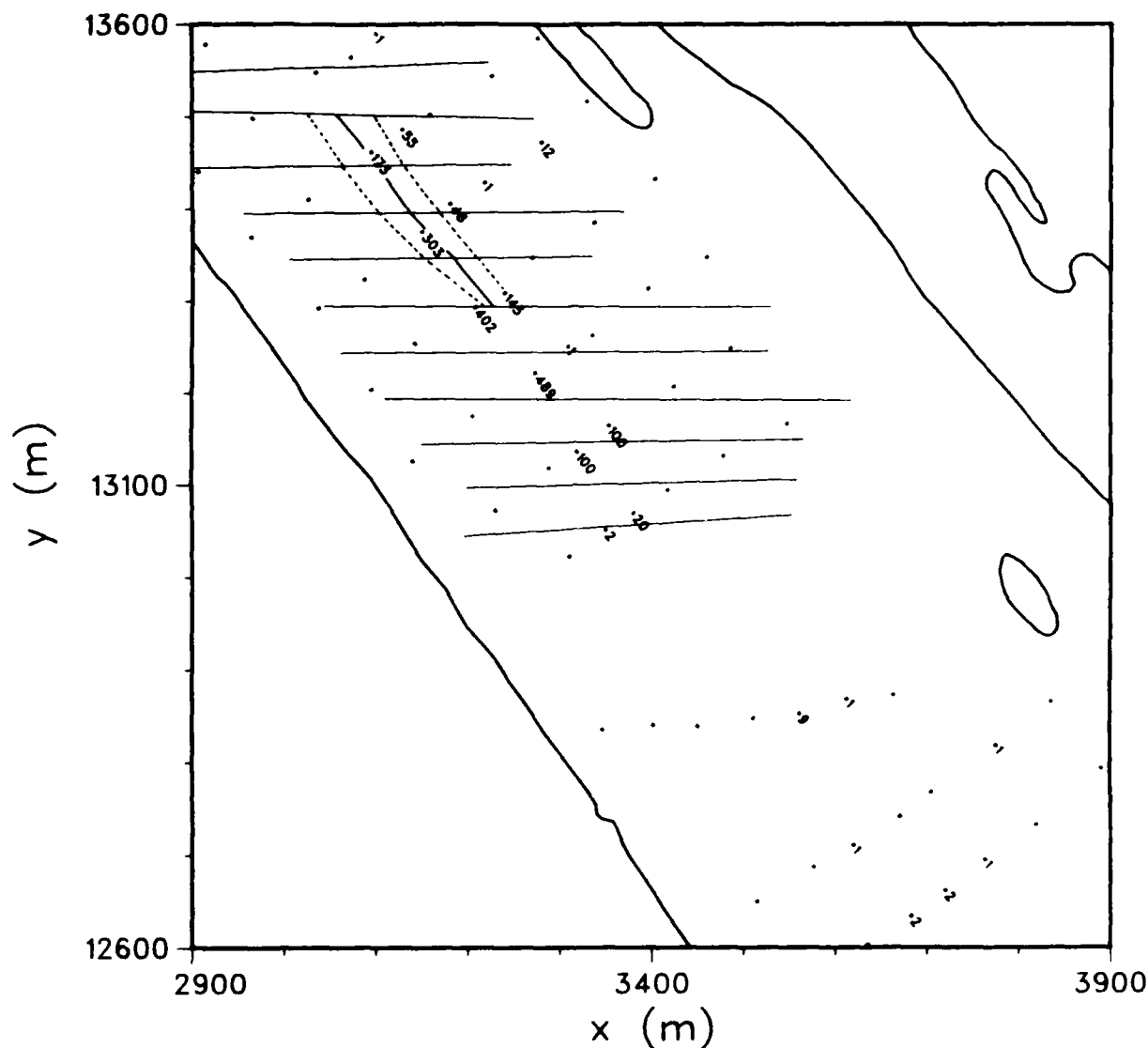
## **3.2 RESULTS OF SUBSEQUENT SURVEYS**

### **3.2.1 Results of Survey VIII**

Survey VIII was an abbreviated survey conducted in conjunction with and in support of the coring operation. Surficial bottom samples were collected on August 23-24, 1983, just before the start of the coring operation. The main objective of the sampling survey was to verify that the distribution of tagged sand, as defined by the three-dyed-sand-grain contour, had not changed significantly since Survey VII (about 2-1/2 months earlier). About half as many samples were collected as compared with Survey VII, and the locations were concentrated in the thalweg region. Border areas and the area downstream of the three-dyed-sand-grain contour were not heavily sampled.

The bathymetric measurements associated with Survey VIII were made on September 1, 1983, immediately after the coring operation. The transverse and longitudinal transects followed in Survey VII were repeated in Survey VIII; results are shown in Fig. 15 and in Sec. A.1 of App. A. The results from the transverse transects indicate little systematic change since Survey VII, and the same wavelike structure is still present in the results from the longitudinal transects.

The bottom sampling locations and the three-dyed-sand-grain contour for Survey VIII are shown in Figs. 16 and 17. The contour is not complete near the downstream end because of the abbreviated nature of this survey. Little change had occurred since the previous survey, except that the contour does not appear to be quite as wide, especially near the upstream end. This narrowing may be related to a brief period of higher-than-average flow that occurred in July 1983 (see Fig. 10). The complete results from the

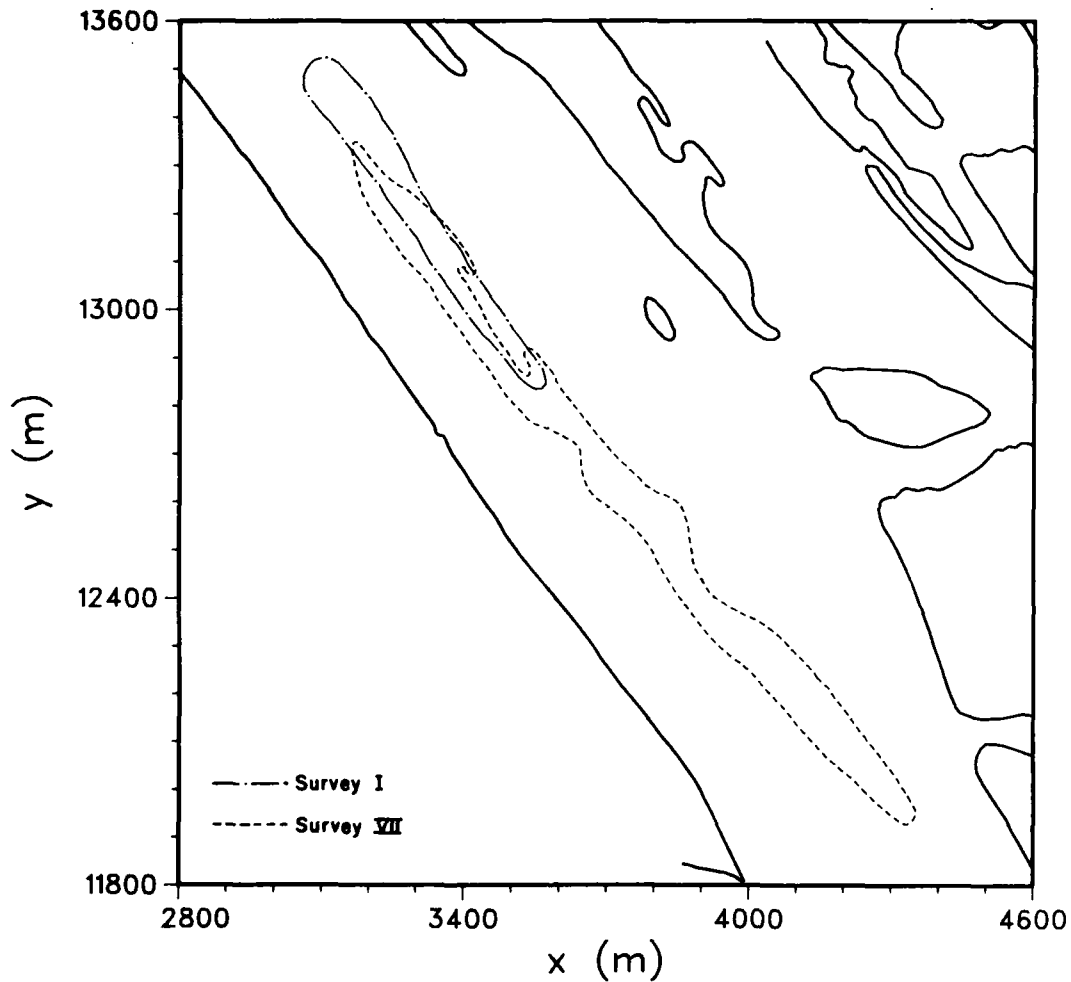


**FIGURE 13 Location of Bathymetric Transects and Bottom Sampling Stations for Survey I at the Gordon's Ferry Disposal Site (location of the pile and the number of dyed sand grains observed are noted)**

bottom sampling survey are given in Sec. A.2 of App. A. Samples were not collected in Stone Slough during this survey.

Figure 18 is a plot of the sediment characteristics of the samples collected on Survey VIII. The key for the sediment classifications used in Fig. 18 and other similar figures in this report is: Y - mud, S - silt, F - fine sand, M - medium sand, C - coarse sand, G - gravel, and R - rock. The bottom material remained mostly medium to coarse sand, although several samples indicated the presence of silt.

The only change apparent on Survey VIII was that the area enclosed by the three-dyed-sand-grain contour was not quite as wide as on the previous survey. The



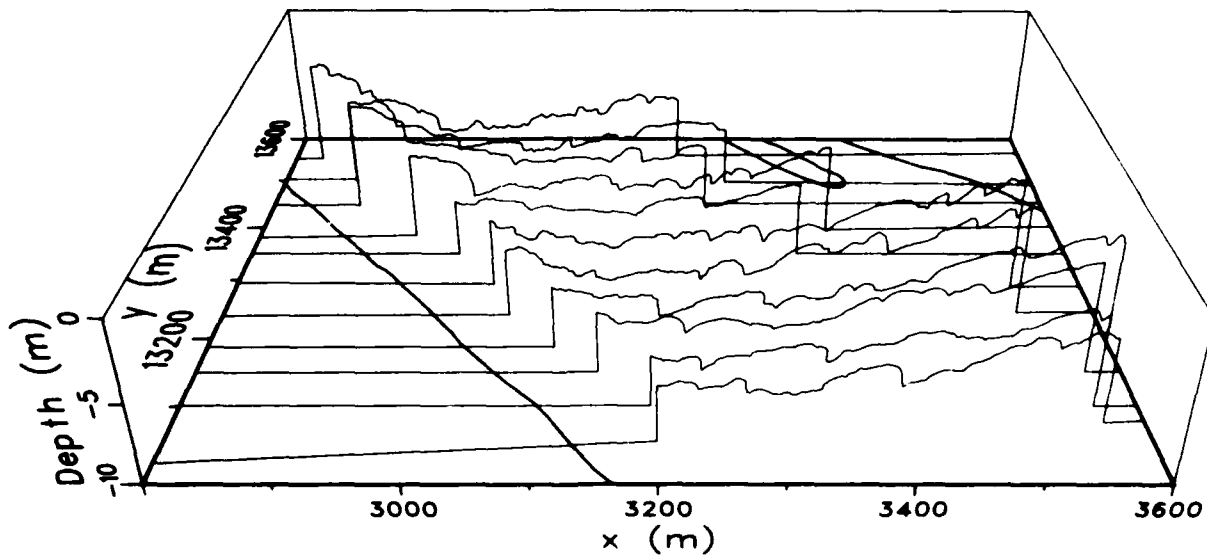
**FIGURE 14** *Distribution of Tagged Sand after Disposal (Survey I) and after the Second Spring Flood (Survey VII) at the Gordon's Ferry Disposal Site*

bathymetric data still indicated the presence of wavelike structures on the bottom in the disposal area, and the bottom material was still predominately medium to coarse sand.

### **3.2.2 Results of Survey IX**

Survey IX was conducted September 18-20, 1984, 1057 days and three spring floods after disposal. No further surveys are planned at the Gordon's Ferry site. The results of the bathymetric survey are shown in Fig. 19, and the individual transects are included in Sec. A.1 of App. A. No significant change in the bottom was apparent since the previous survey; the longitudinal transects exhibited the same wavelike structure that had been apparent on previous surveys.



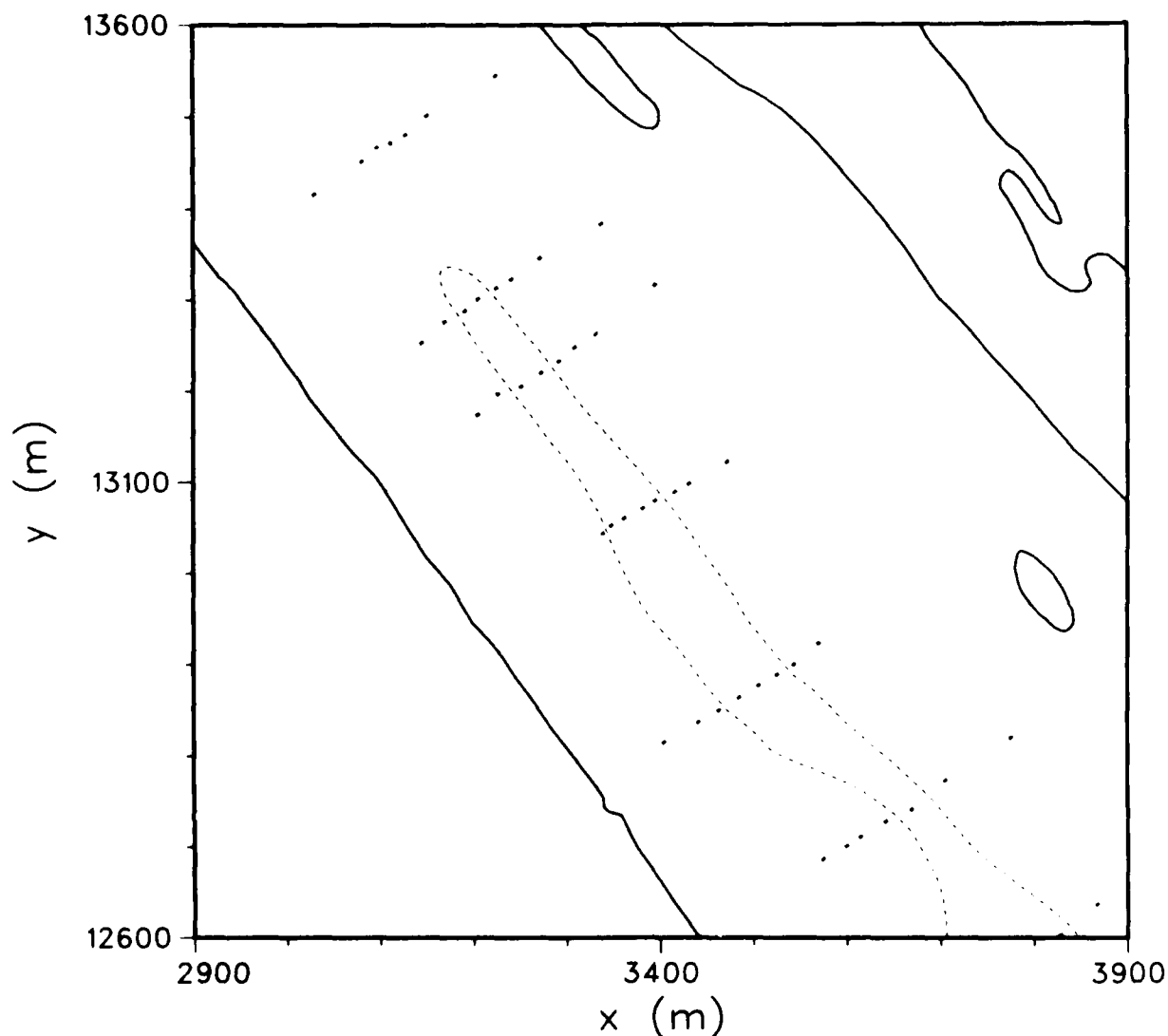


**FIGURE 15 Perspective Plot of Transverse Bathymetric Transects for Survey VIII at the Gordon's Ferry Disposal Site**

Figures 20 and 21 are plots of the bottom sampling locations, with the three-dyed-sand-grain contour drawn. The area enclosed by the contour is about 30% less than it was on Survey VII due to the narrowing of the contour at the upstream end. The length of the contour was essentially unchanged since Survey VII. Complete results of the bottom sampling are given in Sec. A.2 of App. A. No dyed sand was noted in Stone Slough.

The sediment characteristics of the samples collected during Survey IX are indicated in Fig. 22. The bottom sediments remained mostly medium to coarse sand, but many samples contained some silt. The silt was probably deposited as a result of low flows in late summer and early fall.

In summary, Survey IX showed that no change had occurred in the general structure of the bottom at the Gordon's Ferry site. Indeed, since the eradication of the disposal pile during the first spring flood, all bathymetric surveys in the disposal area have provided evidence of the presence of sand dunes, which probably indicated a return to natural bedforms. However, the area of the three-dyed-sand-grain contour decreased by about 30% in the year between Surveys VII and IX. This reduction in area can be attributed to a narrowing of the area enclosed by the contour at the upstream end. Tagged sand near the upstream end was probably being covered by untagged material migrating downstream. An additional consideration was the difficulty of establishing contour boundaries on the later surveys because of the low concentrations of dyed sand and the small concentration gradients. The bottom material in the disposal area remained medium to coarse sand.

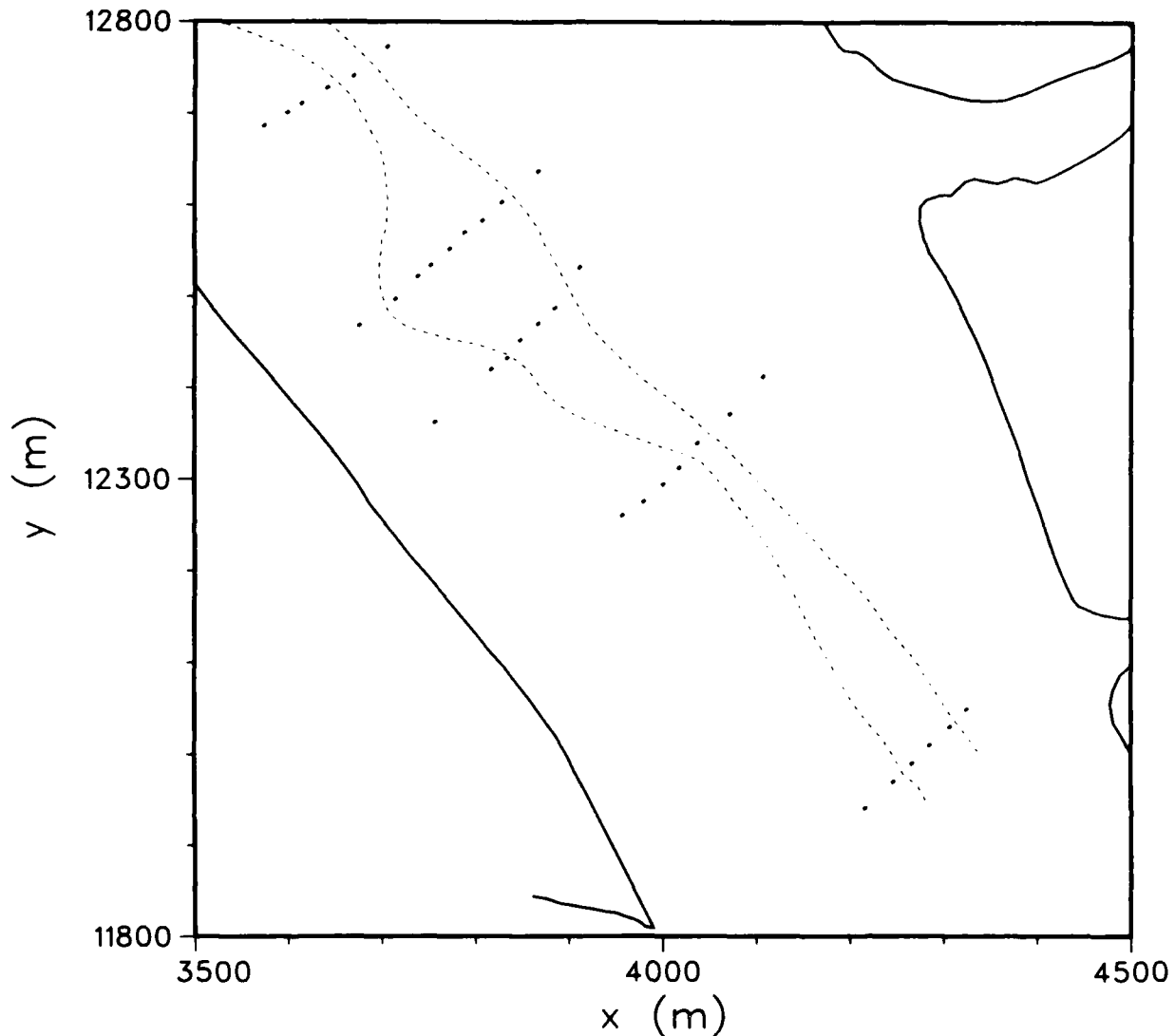


**FIGURE 16 Sampling Locations and the Three-Dyed-Sand-Grain Contour for Survey VIII at the Gordon's Ferry Disposal Site**

### **3.3 RESULTS FROM ANALYSIS OF BOTTOM CORES**

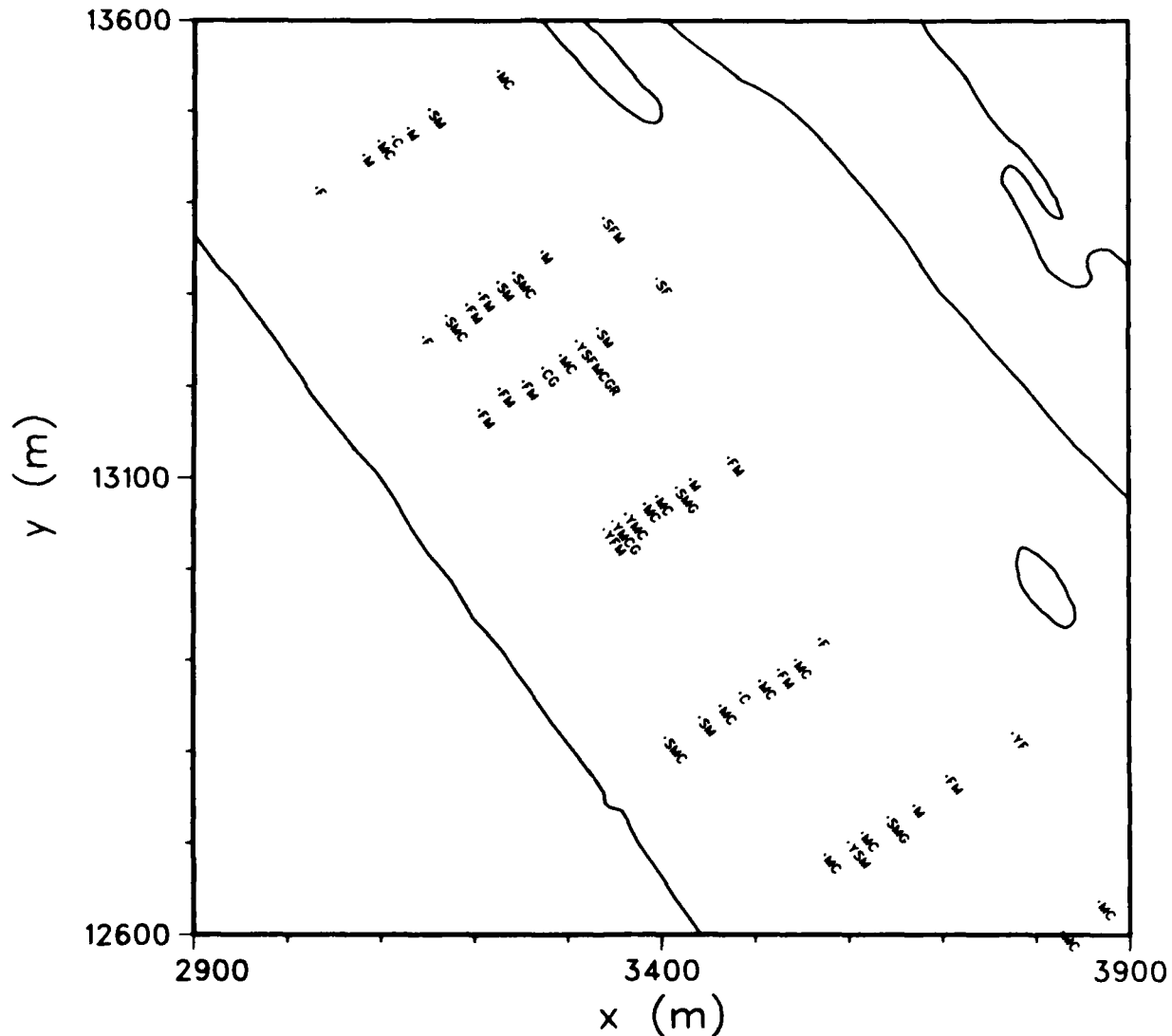
Twenty-five bottom cores were collected at the Gordon's Ferry site on August 24-31, 1984: 19 locations were cored, and duplicate cores were taken at six of the locations. Figure 23 shows the coring locations and indicates whether single or duplicate cores were collected. The bathymetry transects associated with each of the coring locations are also shown.

Coring sites were selected based on the original location of the disposal pile, the original extent of the tagged sand, and the extent of the tagged sand detected in surficial samples in each survey through Survey VII. Figure 24 shows the coring locations superimposed on the outline of the original disposal pile, the original three-dyed-sand-grain contour (Survey I), and the three-dyed-sand-grain contour from Survey VII.



**FIGURE 17 Sampling Locations and the Three-Dyed-Sand-Grain Contour for Survey VIII Downstream of the Gordon's Ferry Disposal Site**

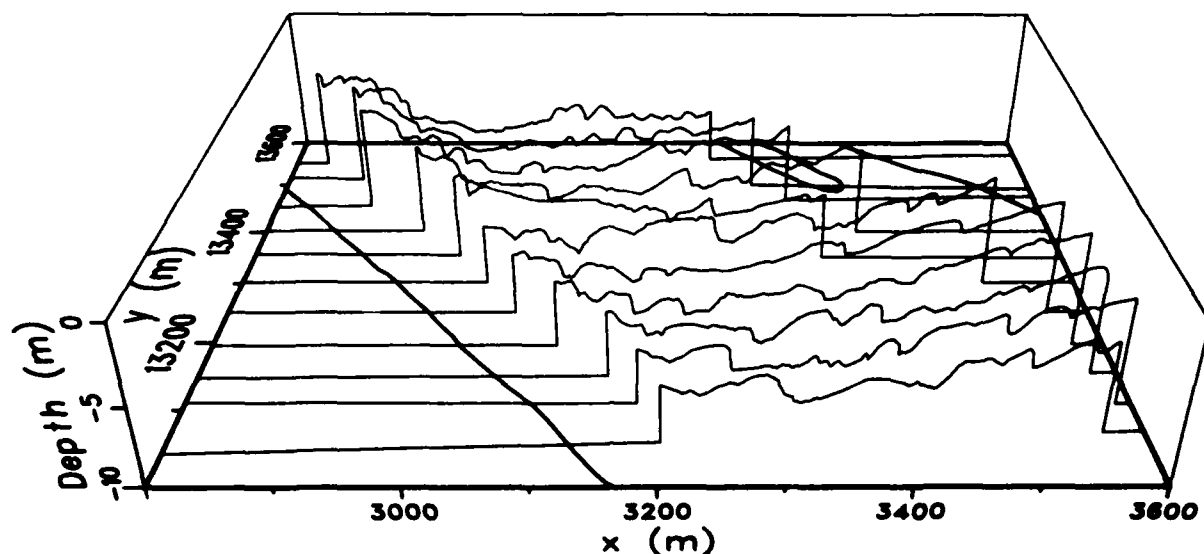
As shown in Fig. 24, the primary coring locations lie along the approximate centerline of the area enclosed by the three-dyed-sand-grain contour (i.e., area of highest counts of dyed sand grains). The cores are designated by Arabic numerals that correspond to the designations of the sampling transects for the bottom sampling surveys. The secondary locations to either side of the approximate centerline locations are designated either NE or SW according to whether they are northeast or southwest of the centerline. For example, core 5NE is located about 20 m northeast of core 5 along transect 5. If two cores were collected at the same location, they are designated by an A or B after the core location number. All duplicate cores were collected at the centerline locations.



**FIGURE 18 Approximate Classification of Bottom Sediments at Sampling Locations for Survey VIII at the Gordon's Ferry Disposal Site**

Figure 24 shows that coring locations 3 through 5 are located in the vicinity of the original disposal pile. Coring locations 3 through 10 are within the extent of the original three-dyed-sand-grain contour, and the remaining centerline locations are within the extent of the three-dyed-sand-grain contour of Survey VII. A few of the coring locations, especially the NE and SW locations, are actually either slightly outside of or very near the contours.

A few of the cores contained a few dyed sand grains near the bottom of the core. These dyed sand grains were probably carried to that depth during the coring operation by the core catcher or by the side of the core tube. Although these isolated dyed sand grains are included in the results presented, they are not thought to indicate the presence of tagged dredged sand at the depths at which they were found.

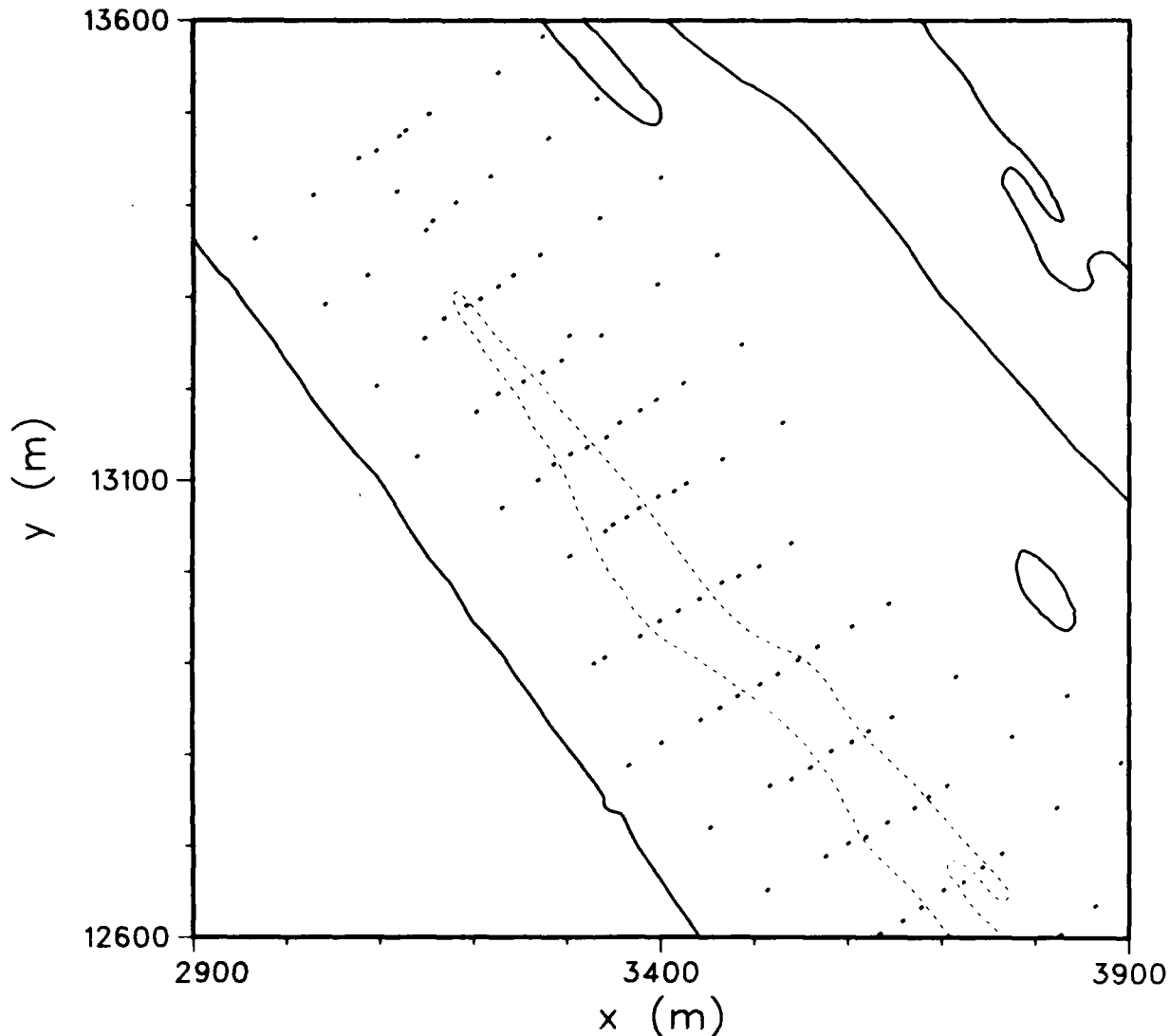


**FIGURE 19 Perspective Plot of Transverse Bathymetric Transects for Survey IX at the Gordon's Ferry Disposal Site**

The results of the analysis for dyed sand within each core and the position of each core relative to the local bottom topography are presented in Figs. 25-43. Table 2 summarizes the core data. The first two columns indicate the core number and the figure number where the details of the core analyses are given. The next column indicates whether the coring location was within the bounds of the initial disposal pile as determined by the bathymetric measurements on Survey I. Columns four and five indicate whether the coring location was inside, outside, or on the three-dyed-sand-grain contour on Surveys I and VII. The next column gives the location of the core with respect to the local dune system; that is, it indicates whether the core was collected in the trough of a dune, in a dune crest, or at some location between a trough and crest. The next to last column reveals the maximum depth at which dyed sand was found in the core. In most instances, dyed sand existed in a continuous layer extending downward from the surface. However, in a few cores, dyed sand layers were separated by layers of undyed material. The final column indicates the number of layers found in such cases.

In the following discussion, dyed sand is considered to be present in a 10-cm core segment if three or more dyed sand grains were visible in a photograph of the sample after it had been spread on the tray. The vertical extent of tagged sand in the bottom sediments has been defined by the same three-dyed-sand-grain limit that was used to define the horizontal extent of tagged sand in the surficial sediments.

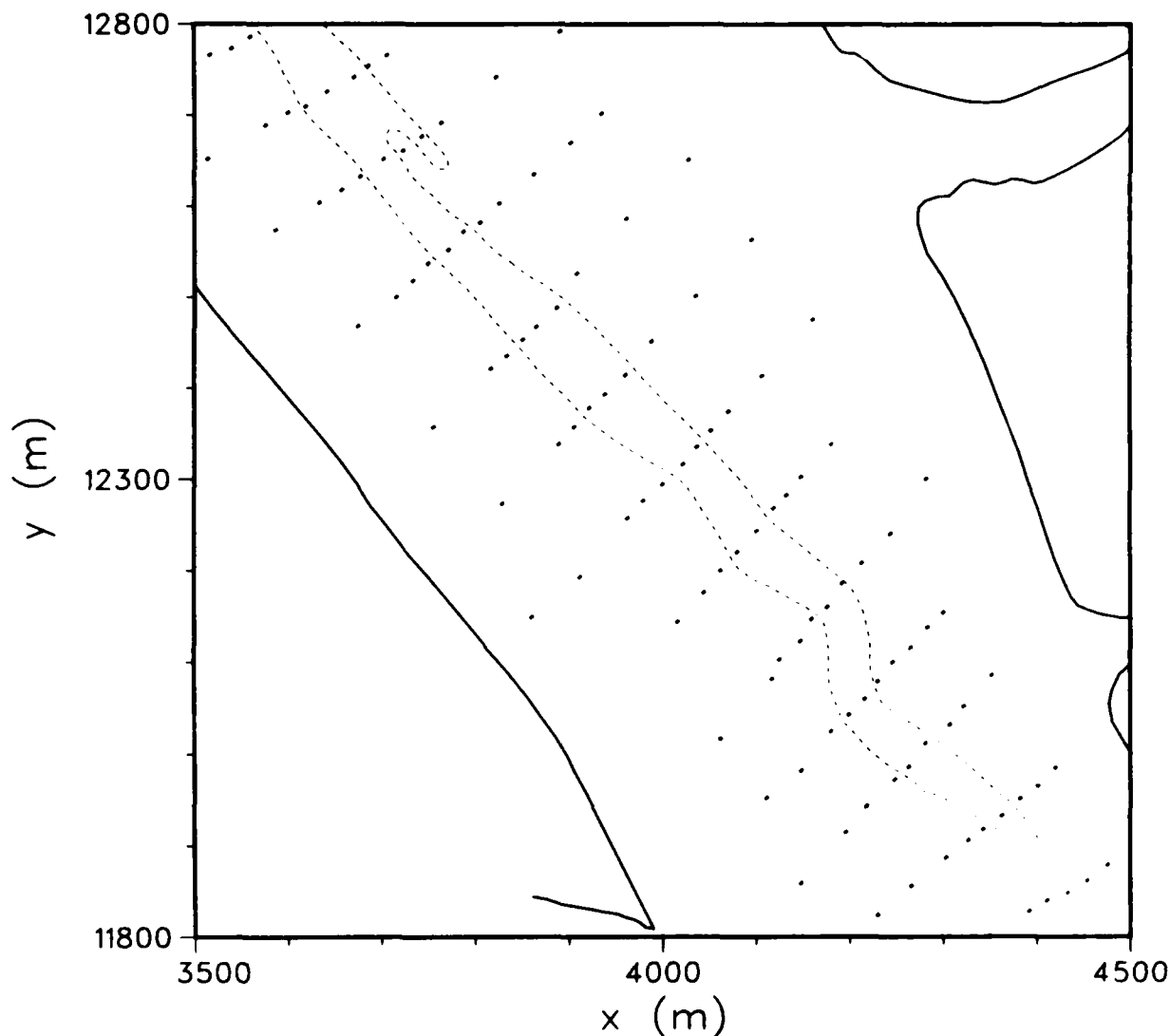
The major finding from the coring experiment was that the dyed sand was located within the dune structures: cores collected in dune troughs contained no dyed sand, and cores not collected in dune troughs contained dyed sand only to a depth approximately corresponding to the elevation of the nearby trough.



**FIGURE 20 Sampling Locations and the Three-Dyed-Sand-Grain Contour for Survey IX at the Gordon's Ferry Disposal Site**

Table 2 and the accompanying figures indicate that only six of the 25 cores contained no dyed sand -- cores 5NE, 7A, 7B, 8SW, 11NE, and 17. Three of those cores (5NE, 8SW, and 17) were collected in dune troughs. Core 11NE was collected in an area that has never been within the three-dyed-sand-grain contour. The reason for the absence of dyed sand in cores 7A and 7B is not clear; however, a positioning error of only 3 m could mean that the cores were collected in a trough rather than near the crest of a dune. The limitations of the positioning system and the presence of river currents could account for a positioning error of this magnitude.

The vertical extent of the dyed sand in all of the other cores collected within the three-dyed-sand-grain contour, as determined for Surveys I or VII, correlated well with the height of the dune at each coring location. In other words, if dyed sand was present



**FIGURE 21 Sampling Locations and the Three-Dyed-Sand-Grain Contour for Survey IX Downstream of the Gordon's Ferry Disposal Site**

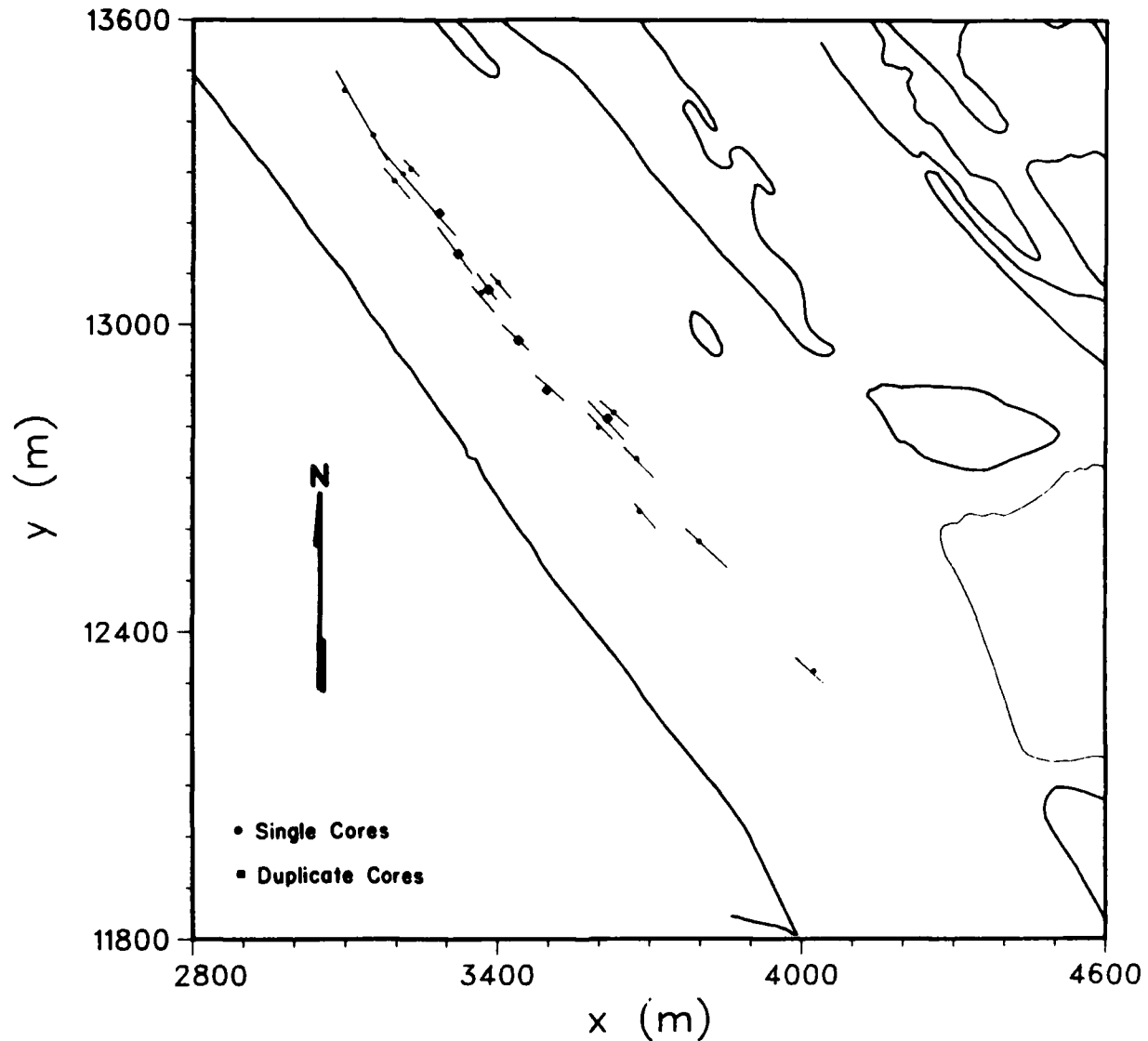
in a core, its vertical extent approximately corresponded to the height of the dune above nearby troughs. Four cores (6A, 6B, 8NE, and 12) collected near a trough contained dyed sand to depths of 30, 30, 40, and 30 cm, respectively. (Core 12 was actually about midway from the trough to the crest, but the dune was small.) The remaining cores were collected at or near dune crests; all contained dyed sand to at least a depth of 70 cm. With the exception of cores collected in troughs, dyed sand was found in all cores taken in locations where dyed sand was found in the surficial bottom sediments.

Some cores contained alternating layers of tagged and untagged material. Cores 3, 4, 5, and 5NE were collected in the area that had been occupied by the disposal pile. With the exception of core 5NE, which was collected in a trough and which contained no dyed sand, these cores contained layers of tagged dredged sand between layers of

untagged material. Although core 13 also shows some evidence of layering, the distinction between the layers is based on small differences in numbers of dyed sand grains per segment and may not be statistically significant.

The layering in cores 3, 4, and 5 is very apparent. Surficial bottom samples collected near the locations of these cores had contained dyed sand in Survey I; however, by Survey VII, they contained fewer than three dyed sand grains. These data suggest that tagged dredged sand has been covered by untagged material moving downstream. Two of these cores contained more than one layer of tagged dredged sand, indicating successive coverings by untagged material and tagged sand from upstream.

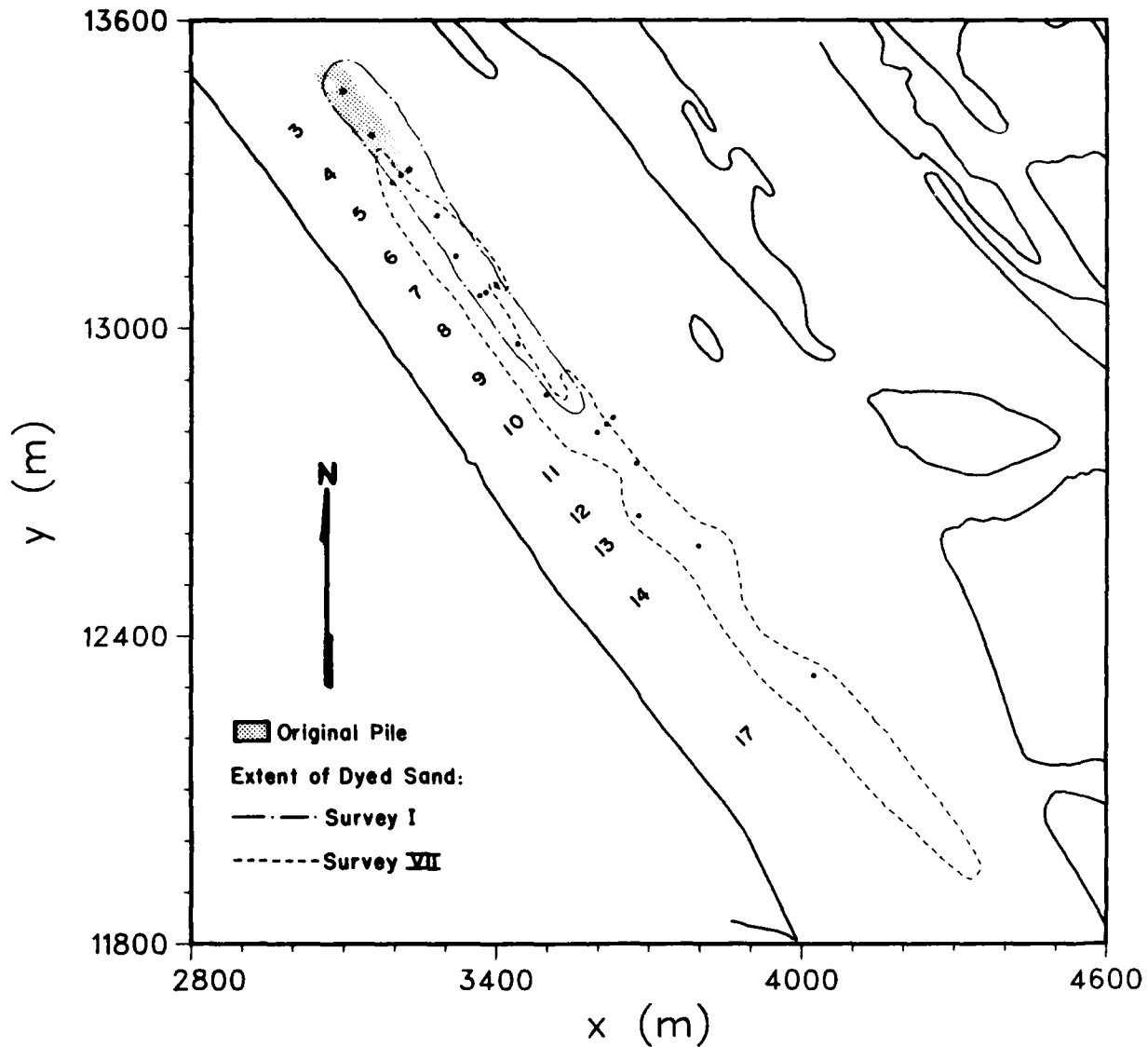




**FIGURE 23 Map of Gordon's Ferry Site Showing Coring Locations and Bathymetric Transects**

In summary, the results from the coring experiment indicate that:

1. Much of the tagged dredged sand that was deposited as a pile in the thalweg during the disposal operation has been incorporated into the dune structures.
2. The tagged dredged sand beneath the river bottom appears to be confined to the dune structures, as little dyed sand was found below dune troughs.
3. The tagged dredged sand still located within the area of the original disposal pile appears to have been successively covered by untagged material and tagged dredged sand from upstream.

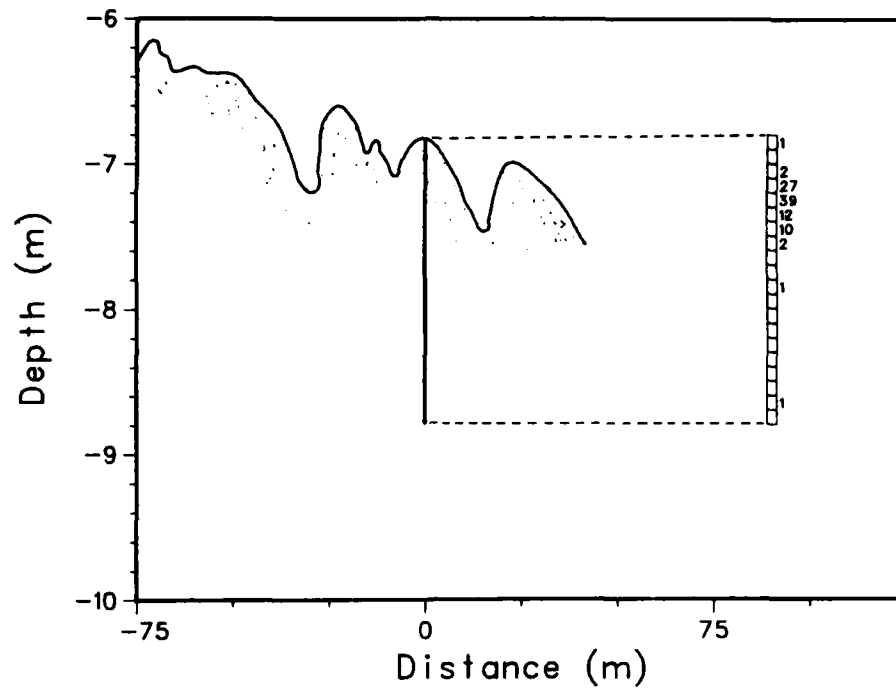


**FIGURE 24** Map of Gordon's Ferry Site Showing the Coring Locations, the Original Disposal Pile, and the Three-Dyed-Sand-Grain Contours from Surveys I and VII

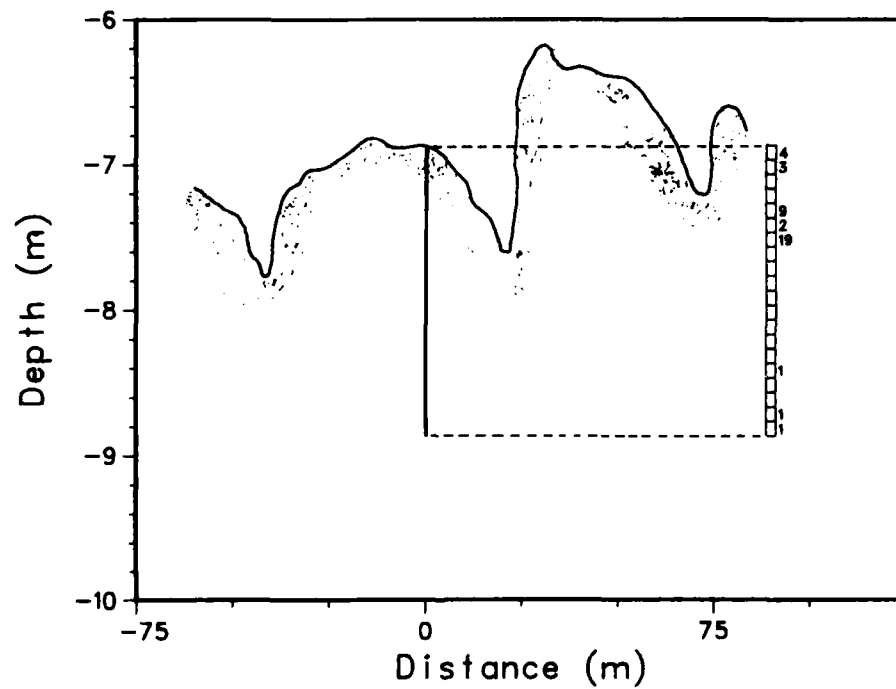
### 3.4 SUMMARY OF GORDON'S FERRY RESULTS

The experiment at the Gordon's Ferry site was initially designed to identify large-scale migration of tagged sand from the original disposal area into main-channel border areas, backwaters, and sloughs. After a few surveys, it was apparent that such migration had not occurred. The experimental plan was then modified to focus more on measurements in the vicinity of the disposal pile.

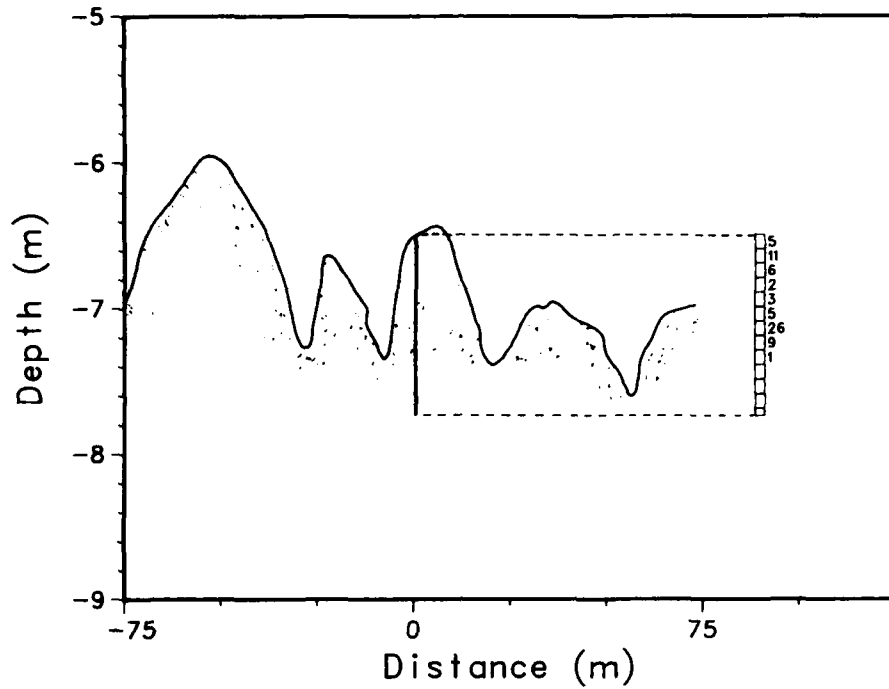
Surficial sediments were sampled at the site over about a two-year period after the initial location of the tagged dredged sand following the dredging operation had been determined. The bottom-sampling surveys showed that the sand had not moved far, and



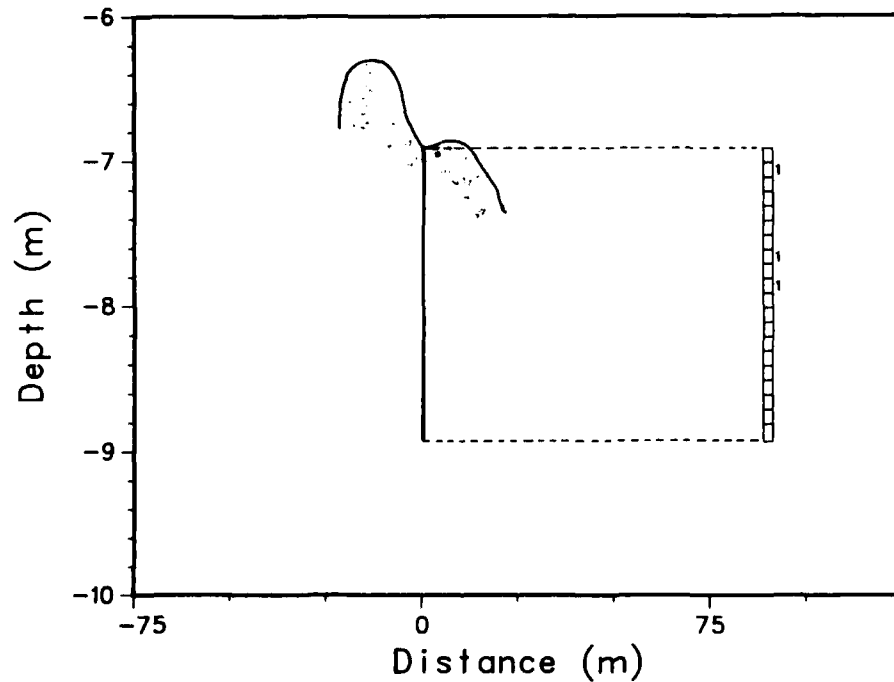
**FIGURE 25** Plot Showing Distribution of Dyed Sand in Core 3 and Core Position Relative to Bottom Topography



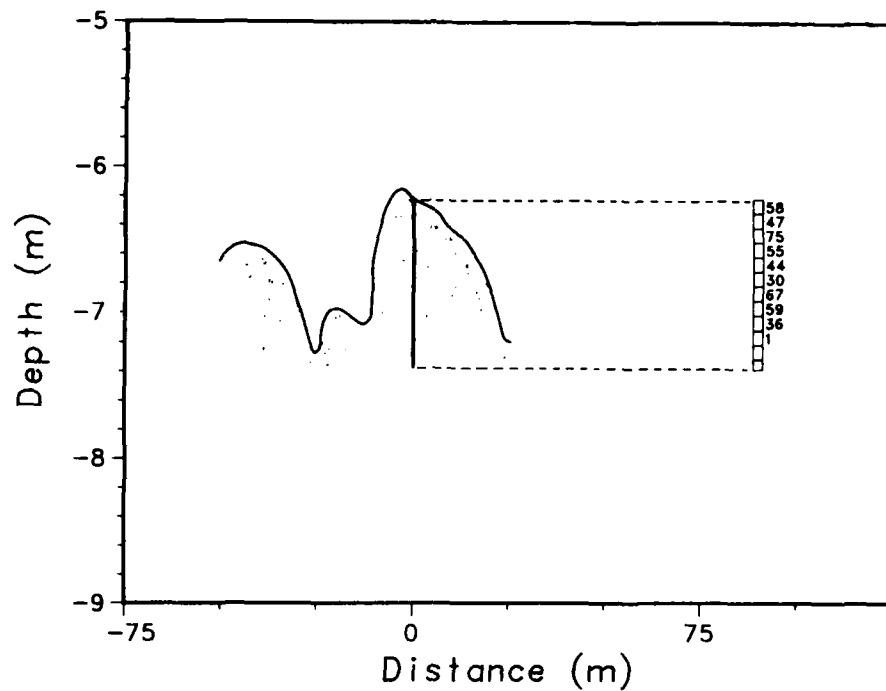
**FIGURE 26** Plot Showing Distribution of Dyed Sand in Core 4 and Core Position Relative to Bottom Topography



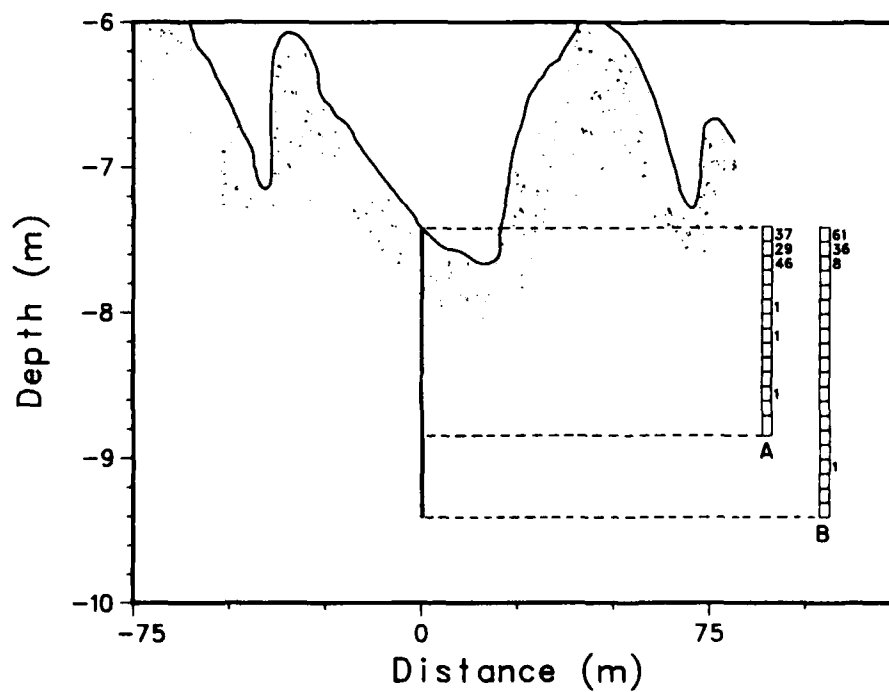
**FIGURE 27** Plot Showing Distribution of Dyed Sand in Core 5 and Core Position Relative to Bottom Topography



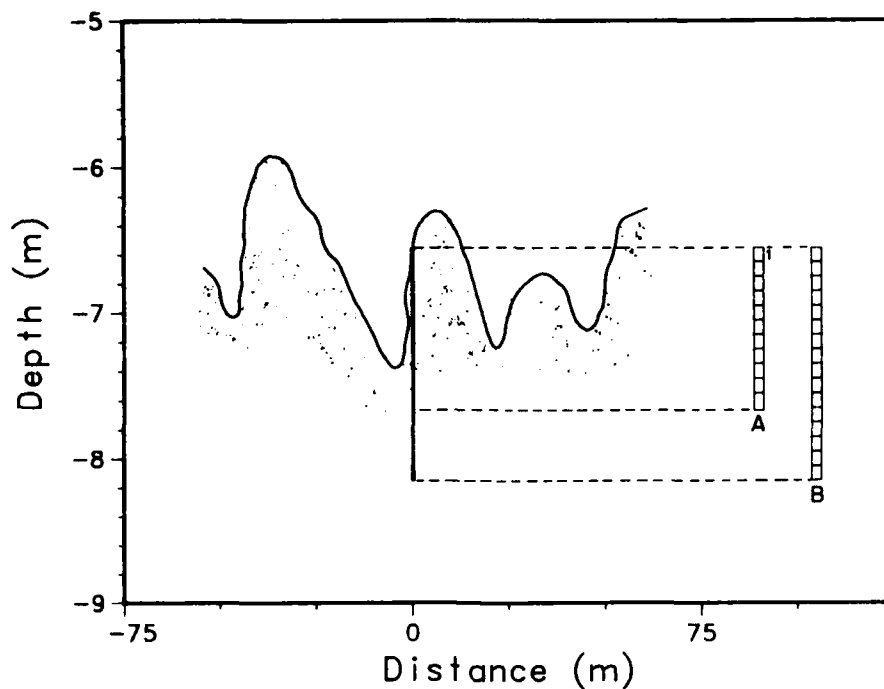
**FIGURE 28** Plot Showing Distribution of Dyed Sand in Core 5NE and Core Position Relative to Bottom Topography



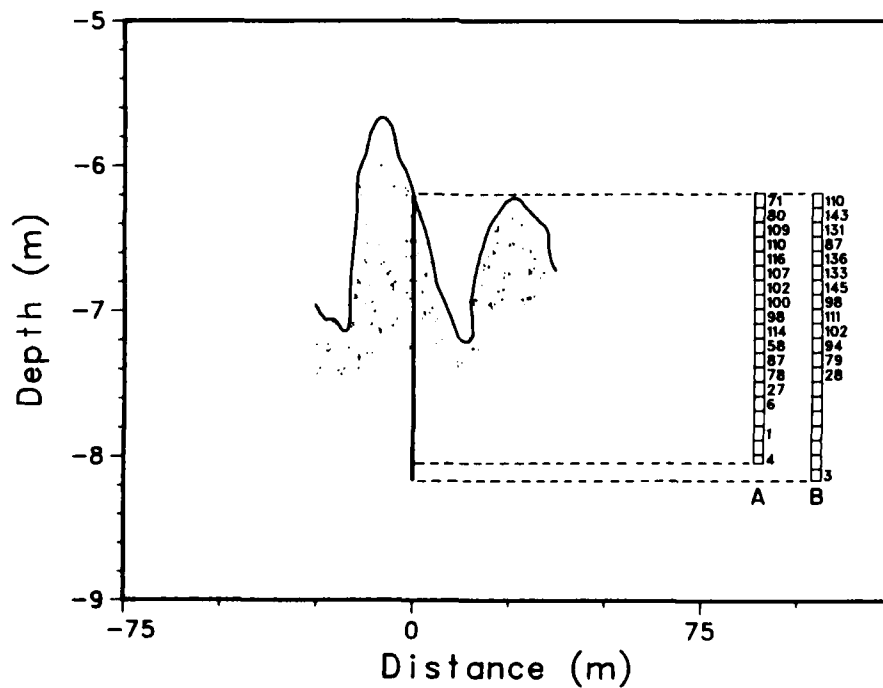
**FIGURE 29** Plot Showing Distribution of Dyed Sand in Core 5SW and Core Position Relative to Bottom Topography



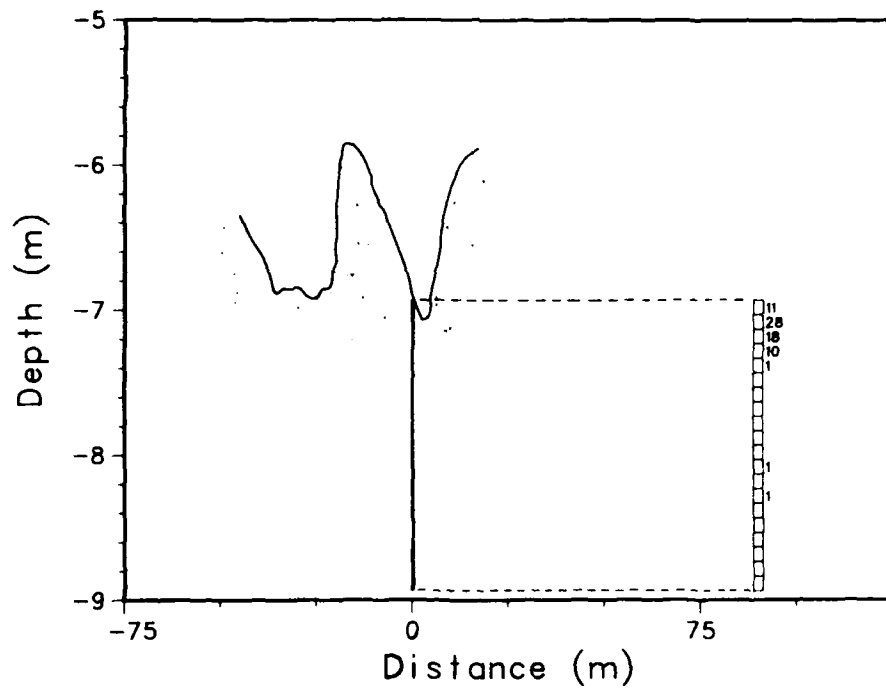
**FIGURE 30** Plot Showing Distribution of Dyed Sand in Cores 6A and 6B and Core Position Relative to Bottom Topography



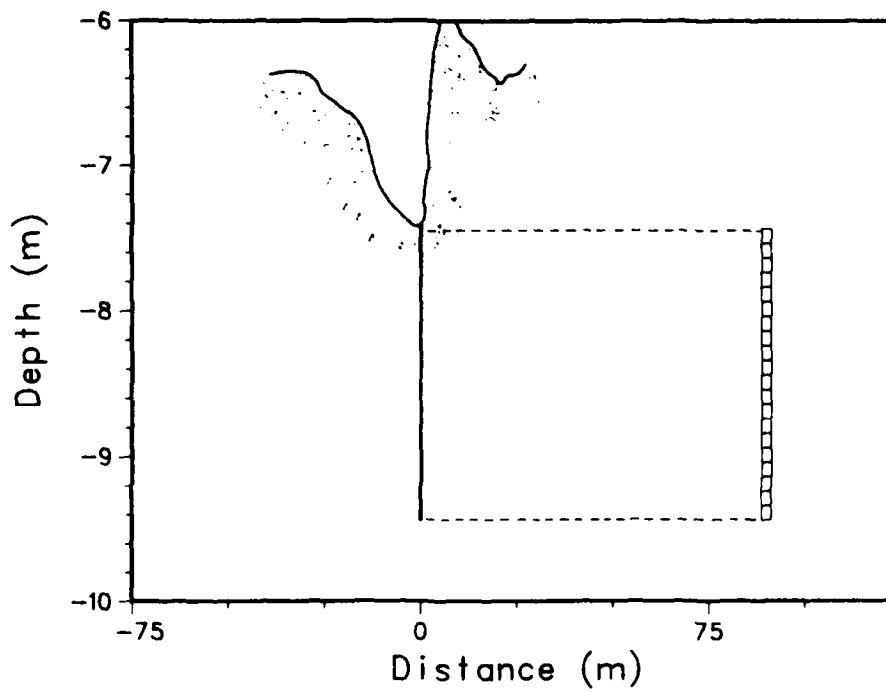
**FIGURE 31 Plot Showing Distribution of Dyed Sand in Cores 7A and 7B and Core Position Relative to Bottom Topography**



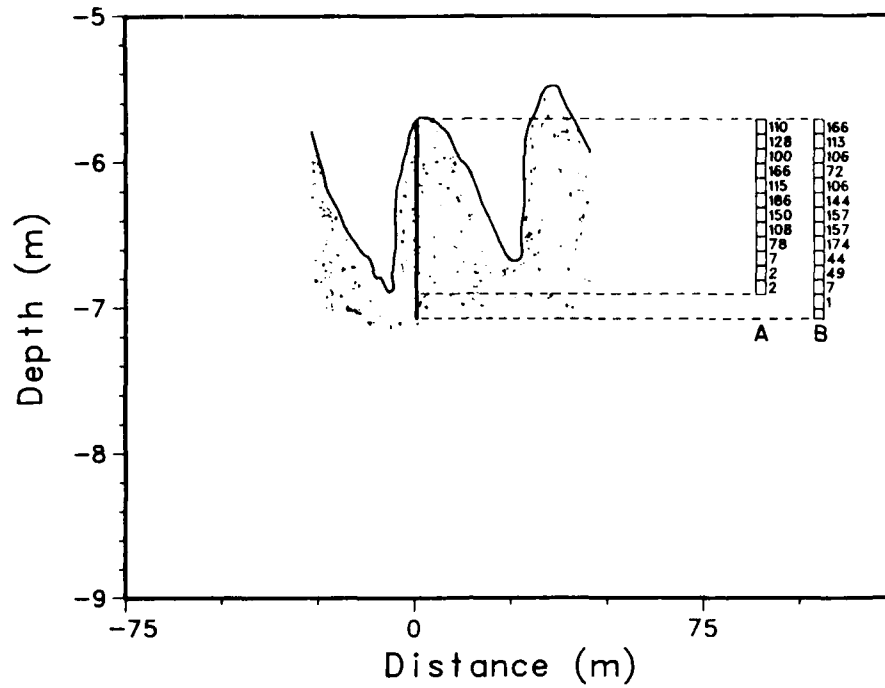
**FIGURE 32 Plot Showing Distribution of Dyed Sand in Cores 8A and 8B and Core Position Relative to Bottom Topography**



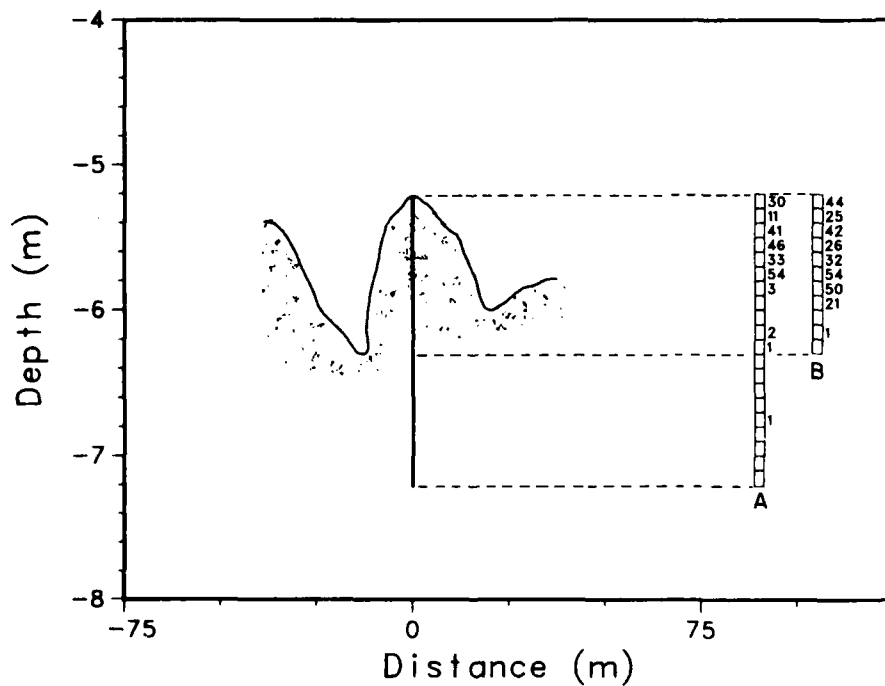
**FIGURE 33** Plot Showing Distribution of Dyed Sand in Core 8NE and Core Position Relative to Bottom Topography



**FIGURE 34** Plot Showing Distribution of Dyed Sand in Core 8SW and Core Position Relative to Bottom Topography

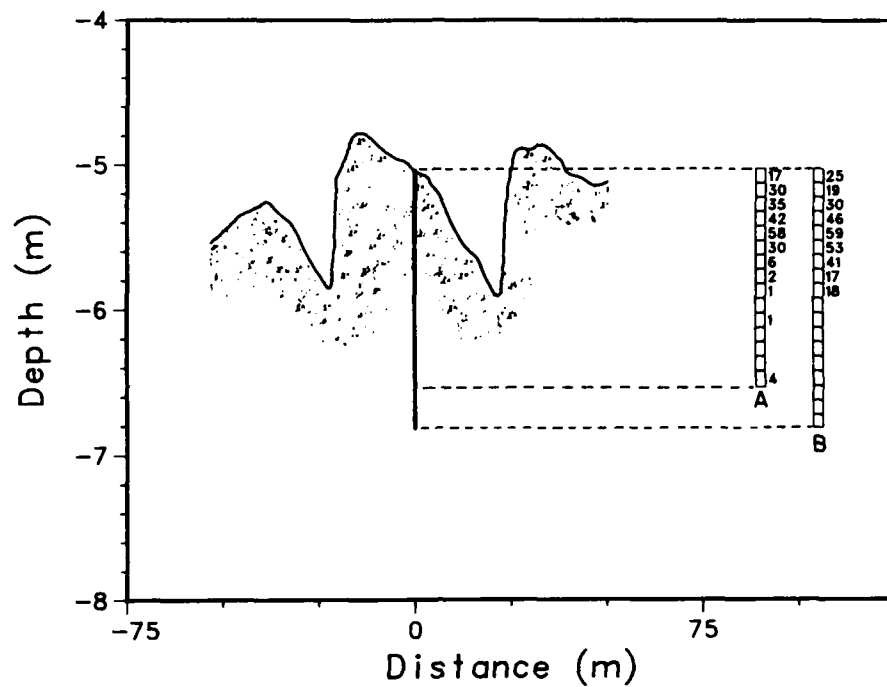


**FIGURE 35** Plot Showing Distribution of Dyed Sand in Cores 9A and 9B and Core Position Relative to Bottom Topography

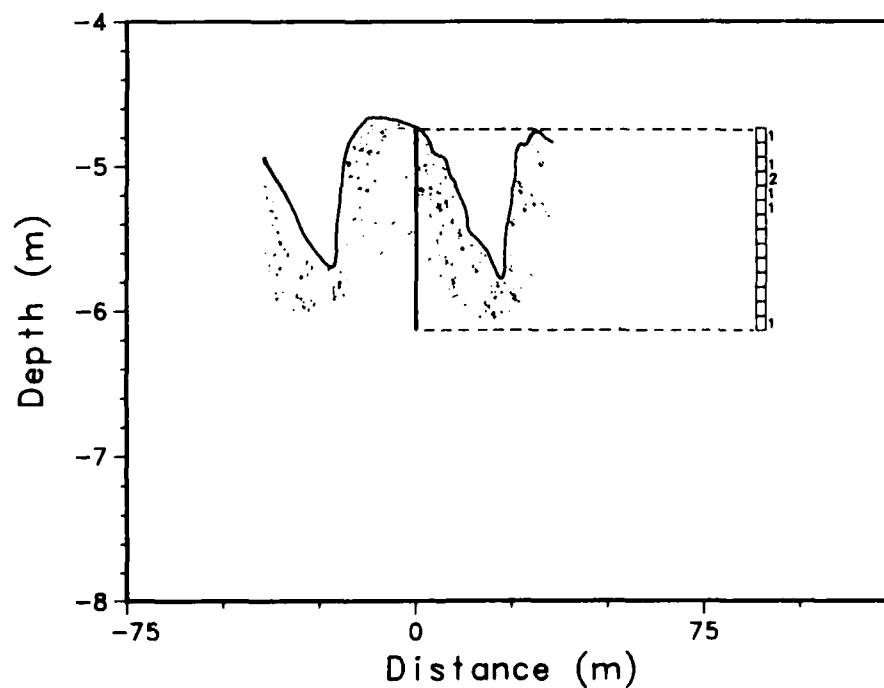


**FIGURE 36** Plot Showing Distribution of Dyed Sand in Cores 10A and 10B and Core Position Relative to Bottom Topography

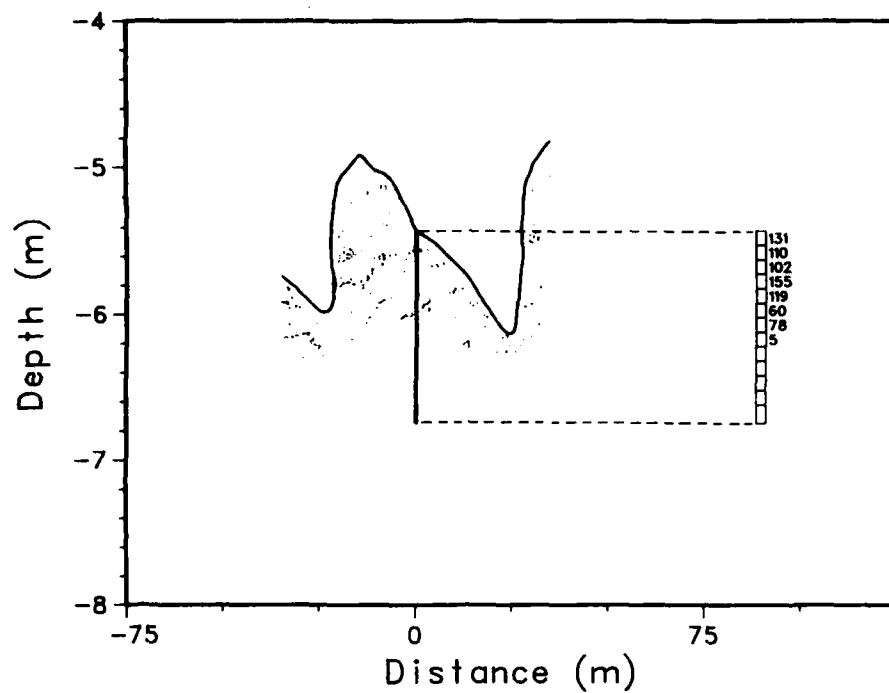




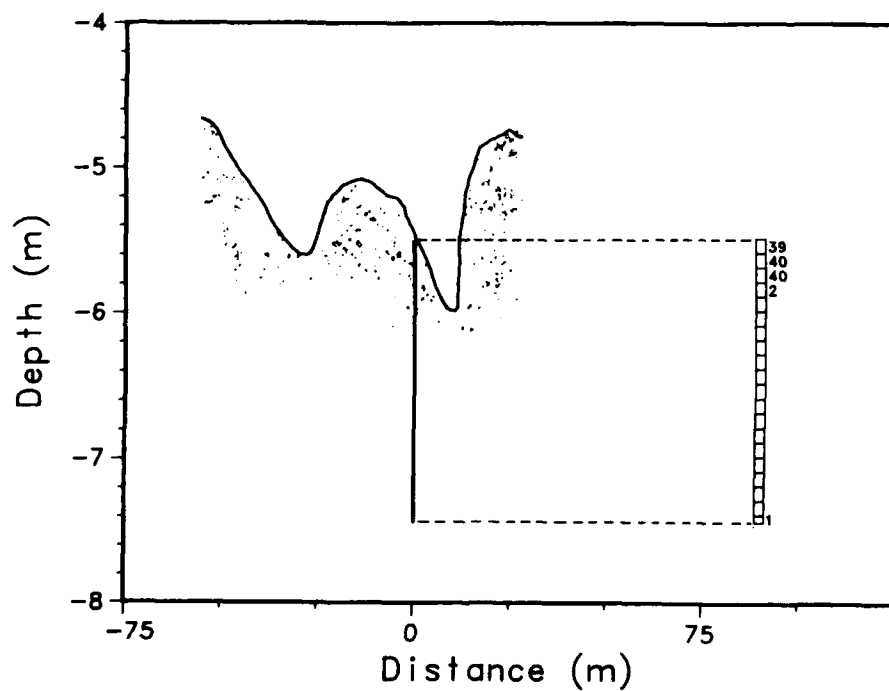
**FIGURE 37** Plot Showing Distribution of Dyed Sand in Cores 11A and 11B and Core Position Relative to Bottom Topography



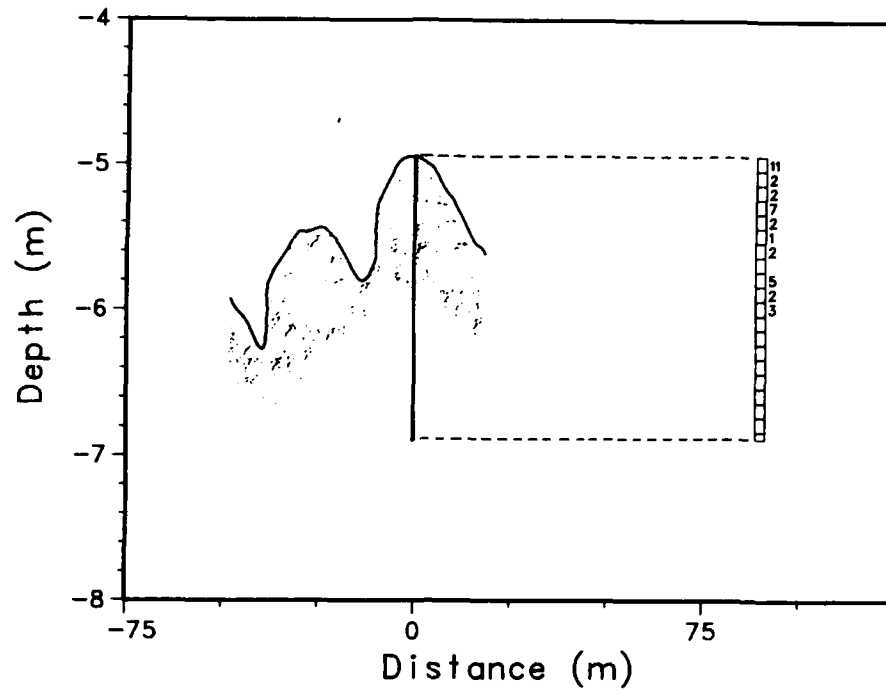
**FIGURE 38** Plot Showing Distribution of Dyed Sand in Core 11NE and Core Position Relative to Bottom Topography



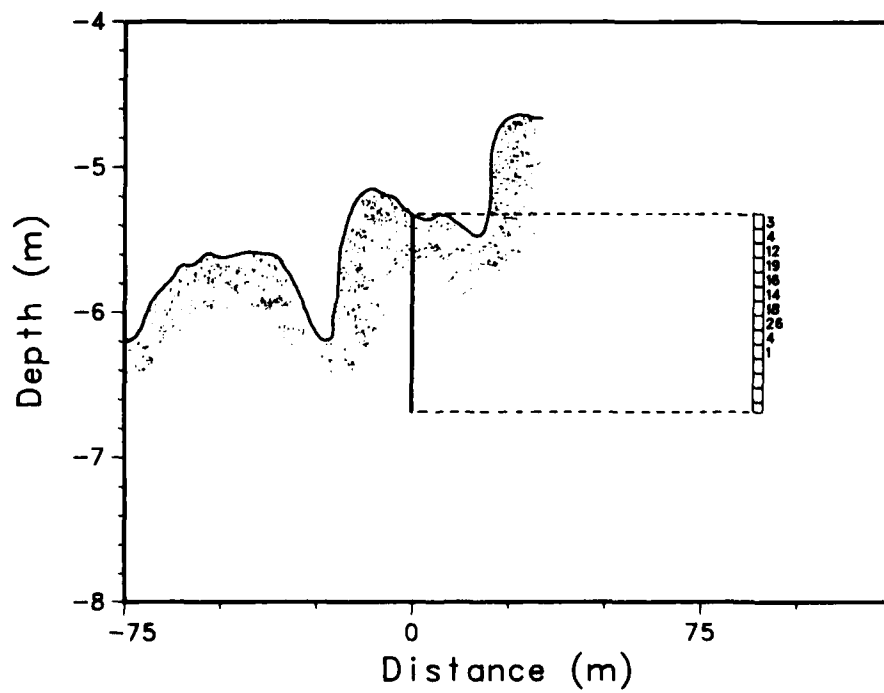
**FIGURE 39 Plot Showing Distribution of Dyed Sand in Core 11SW and Core Position Relative to Bottom Topography**



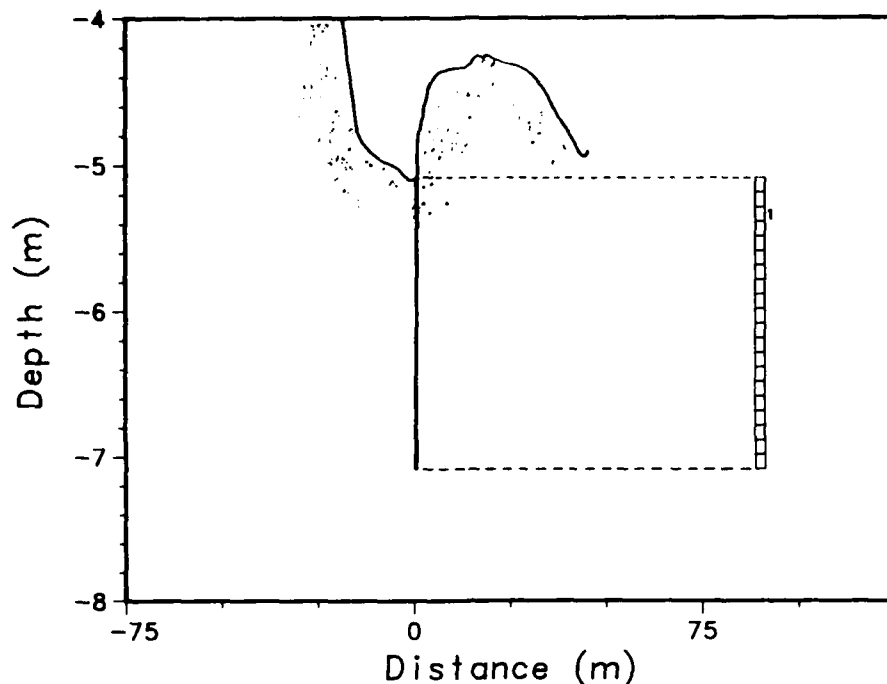
**FIGURE 40 Plot Showing Distribution of Dyed Sand in Core 12 and Core Position Relative to Bottom Topography**



**FIGURE 41 Plot Showing Distribution of Dyed Sand in Core 13 and Core Position Relative to Bottom Topography**



**FIGURE 42 Plot Showing Distribution of Dyed Sand in Core 14 and Core Position Relative to Bottom Topography**



**FIGURE 43 Plot Showing Distribution of Dyed Sand in Core 17 and Core Position Relative to Bottom Topography**

the bathymetric measurements showed that dunes had developed in the disposal area. However, the surficial bottom samples provided no information regarding the vertical distribution of tagged sand within the bottom sediments. It was decided that a limited investigation of the vertical distribution of the tagged sand would provide some insight into how the dredged sand had become incorporated into the river bottom.

In August 1983, 25 bottom cores were collected at 19 locations in the original disposal area and in downstream areas where surficial sediments contained dyed sand. Bathymetry was measured near the coring locations so that the cores could be related to the local dune structure.

Results from the bathymetric surveys at Gordon's Ferry indicated that the disposal pile remained a distinct topographic feature until the first major flood, which occurred in the spring of 1982. After that flood, the bathymetric signature of the pile was lost. The sand dunes that developed in the disposal area probably represent the natural condition of the bottom there. No significant changes have been noted in the bathymetric measurements since the spring flood of 1982.

Flooding also accounted for the major changes in the areal extent of the dyed sand. Little change in the area of the three-dyed-sand-grain contour was noted until after the second spring flood, in the spring of 1983, when the area was found to have doubled. On the final survey, the width of the contoured region near the upstream end had decreased, causing a decrease in area of about 30%. This narrowing was probably a result of untagged material moving downstream and covering tagged sand. The layering

TABLE 2 Summary of Core Data

Core	Fig. No.	Within Initial Disposal Pile Boundary	<u>Within Three- Dyed-Sand- Grain Contour</u>		Vertical Location in Dune Structure	Maximum Depth of Dyed Sand (cm)	Number <sup>a</sup> of Layers
			Survey I	Survey VII			
3	25	Yes	Yes	No	Crest	70	1
4	26	Yes	Yes	No	Crest	70	2
5	27	Yes	Yes	On	Crest	80	1
5NE	28	Yes	Yes	No	Trough	0	0
5SW	29	No	On	Yes	Crest	90	0
6A,B	30	No	Yes	Yes	Near trough	30	0
7A,B	31	No	Yes	Yes	Near crest	0	0
8A,B	32	No	Yes	Yes	Near crest	150	0
8NE	33	No	Yes	On	Near trough	40	0
8SW	34	No	Yes	Yes	Trough	0	0
9A,B	35	No	Yes	Yes	Crest	120	0
10A,B	36	No	On	Yes	Crest	80	0
11A,B	37	No	No	On	Near crest	90	0
11NE	38	No	No	No	Crest	0	0
11SW	39	No	No	Yes	Midway	80	0
12	40	No	No	Yes	Midway	30	0
13	41	No	No	Yes	Crest	110	3
14	42	No	No	Yes	Near crest	90	0
17	43	No	No	Yes	Trough	0	0

<sup>a</sup>Excluding the surface layer.

noted in the cores from this upstream area supports this hypothesis. The downstream extent of the contour has not changed substantially since the 1983 spring flood, although the number of dyed sand grains per sample within the downstream portion of the contour appears to have increased slightly from approximately 3 to 10-20.

During the first seven surveys, the characteristics of the bottom sediments in the disposal area changed gradually from almost exclusively fine sand on Surveys I and II to a mixture of medium to coarse sand on Survey VII. No further changes were noted on the last surveys.

Analyzing the cores for dyed sand established that virtually all of the tagged sand remaining as a coherent patch in the thalweg resides within the dune structure along the river bottom. Within the limits of the experiment, most of the dyed sand in the cores was found in the dunes themselves and little was found at depths below the troughs of the local dune structure. The dredged sand, which was deposited as a pile along the thalweg, has apparently evolved into dunes that migrate downstream.

Four cores were collected in the area originally occupied by the disposal pile, where very little dyed sand had been found in the surficial sediments on Survey VII. Data from some of these cores suggest that tagged sand had been covered by untagged material from upstream. Core 3, the one collected farthest upstream, contained a layer of tagged sand overlain by about 30 cm of untagged material. Cores 4 and 5 contained several layers of tagged sand interlayered with untagged material.

In summary, the results from the nine surveys at the Gordon's Ferry site over almost a three-year period can be summarized as follows:

1. No evidence was found of large-scale migration of dredged sand into biologically sensitive main-channel border areas, backwaters, or sloughs.
2. The disposal pile, which was originally quite distinct bathymetrically, lost its topographic signature after the first spring flood. Sand dunes developed in the disposal area.
3. The areal extent of the tagged sand, as defined by the three-dyed-sand-grain contour, showed little change through Survey VI. Between Surveys VI and VII, the contour was found to have elongated in the downstream direction by a factor of two. This doubling probably occurred in response to flooding in the spring of 1983. Since Survey VII the areal extent of the tagged sand has decreased by about 30%, due mainly to a narrowing of the contoured area near the upstream end. This narrowing was probably caused by untagged material from upstream covering tagged sand.
4. Analysis of the bottom cores indicated that much of the tagged dredged sand remained within the dune structure and is apparently migrating downstream with the dunes. Tagged sand near the

upstream portion of the original disposal pile has been overlain, sometimes more than once, by untagged material migrating downstream.

5. The bottom sediments in the original disposal area gradually changed from fine to coarse sand.

#### 4 FIELD EXPERIMENTS AND RESULTS AT WHITNEY ISLAND

Section 4.1 reviews the dredging, tagging, and disposal operations, and the results from Surveys I-V at the Whitney Island site, which are described in detail in ANL/EES-TM-270, Vol. 1.<sup>1</sup> Detailed results of the two additional surveys are discussed in Sec. 4.2, and all of the Whitney Island results are summarized in Sec. 4.3.

Table 3 presents background information on the experimental activities that took place at Whitney Island. Figure 44 is the river hydrograph measured at Lock and Dam 22 by the Rock Island District, about 19 km downstream from the disposal site.

##### 4.1 REVIEW OF DREDGING, TAGGING, AND DISPOSAL OPERATIONS, AND SUMMARY OF SURVEYS I-V

The dyed sand that was used to tag the dredged material was mostly medium sand. It was chosen to match the dredged sand as closely as possible. During the dredging operation, 6500 kg of dyed sand was mixed with the dredged sand to yield an average concentration by weight of about 90 ppm. The dredging and disposal operation took place on September 14-18, 1982, at the location indicated in Fig. 45.

The bathymetric survey immediately following the disposal operation showed that a series of overlapping mounds with a total length of about 600 m had been formed. This configuration was different from the single elongated pile formed at the Gordon's Ferry site. The disposal pile was located in a region where the natural water depth ranged from about 5.7 to 7.3 m. The height of the pile above the local natural bottom was 0.7-5.3 m, with an average height of 3.0 m. The width of the pile at the base was 40-80 m, with an average width of about 60 m. Figure 46 shows some of the results from this bathymetric survey in the form of a perspective plot, with the base of the plot set arbitrarily at a depth of 10 m.

Figure 47 shows the bottom sampling locations, the number of dyed sand grains observed on the surface of the 23 x 23 cm sample tray at each location, the paths of the bathymetric transects, and the location of the peak and the lateral extent of the disposal pile as determined from the bathymetric survey. An area containing samples with significant counts of dyed sand (>3) extended about 200 m downstream of where the physical pile appeared on the bathymetric transects.

The topographically distinguishable disposal pile remained a distinct bathymetric feature until the first period of high flow after disposal (see Fig. 44), which took place in December 1982. Prior to the December flood, some decrease in the heights of the higher peaks of the pile had occurred. However, after the December flood, the recognizable pile had disappeared, and the average bottom elevation in the disposal area returned to about its predisposal value. Dune structures were apparent along the bottom.

The December 1982 flood was followed by a spring flood of even greater magnitude (about a 50-year flood) and of longer duration than the previous flood. The survey after the spring flood (Survey V) indicated that the average bottom elevation had decreased by about 0.5 m.



**TABLE 3 Experimental Activities at the Whitney Island Disposal Site**

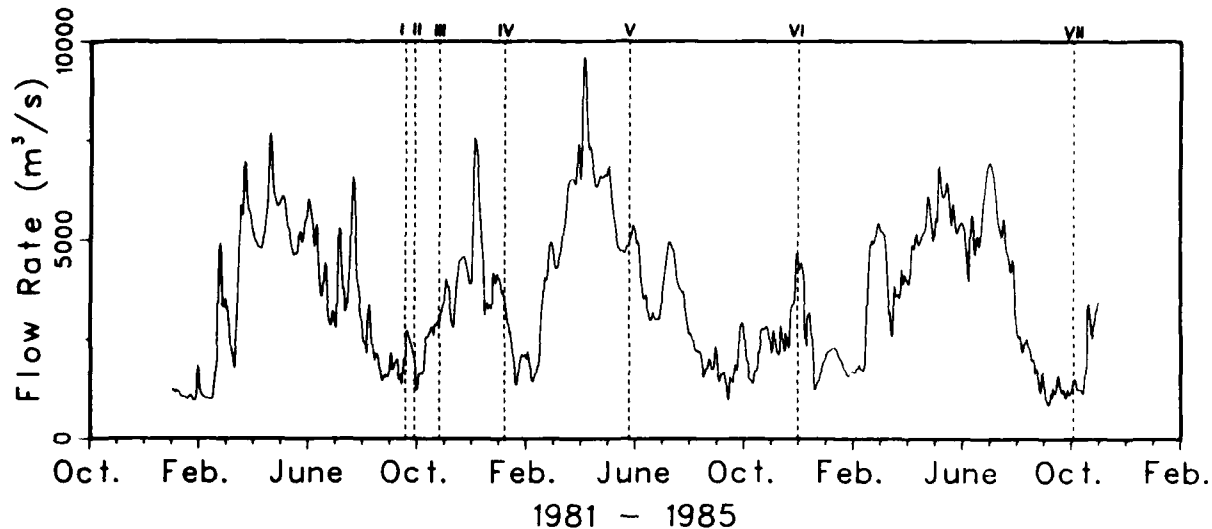
Experimental Activity	Date	Time after Disposal (days) <sup>a</sup>	Number of Bottom Samples Collected
Background bottom samples	September 13, 1982	-5	9
Predisposal bathymetry	September 14, 1982	-4	NA <sup>b</sup>
Dredging and disposal operations	September 14-18, 1982	0	NA
Survey I	September 18-21, 1982	0	115
Survey II	September 28-29, 1982	10	69
Survey III	October 26-27, 1982	38	70
Survey IV	January 5-7, 1983	109	143
Survey V	May 24-26, 1983	249	161
Survey VI	November 29 - December 1, 1983	438	80
Survey VII	October 2-3, 1984	746	108

<sup>a</sup>Time from the end of disposal operations on September 18, 1982.

<sup>b</sup>Not applicable.

The location of the tagged sand, as defined by the three-dyed-sand-grain contour, did not change significantly prior to the December 1982 flood. However, after the December flood, the area of tagged sand had separated into two distinct regions. Figure 48 shows the original three-dyed-sand-grain contour from Survey I and the contour after the December flood (Survey IV). The portion of the area that remained near the original disposal site enclosed an area about half that of the original region; the portion of the area that moved about 0.4 km downstream was about equal to that of the original.

The second major change that occurred between Surveys IV and V was caused by a major spring flood having a return period of about 50 years. Results from Survey V indicated that the tagged sand had virtually disappeared from the original disposal location. The area enclosed by the three-dyed-sand-grain contour was about 40% larger



**FIGURE 44 Mean Daily River Discharge for the Whitney Island Site as Recorded at Lock and Dam 22, with the Dates of the Surveys Indicated**

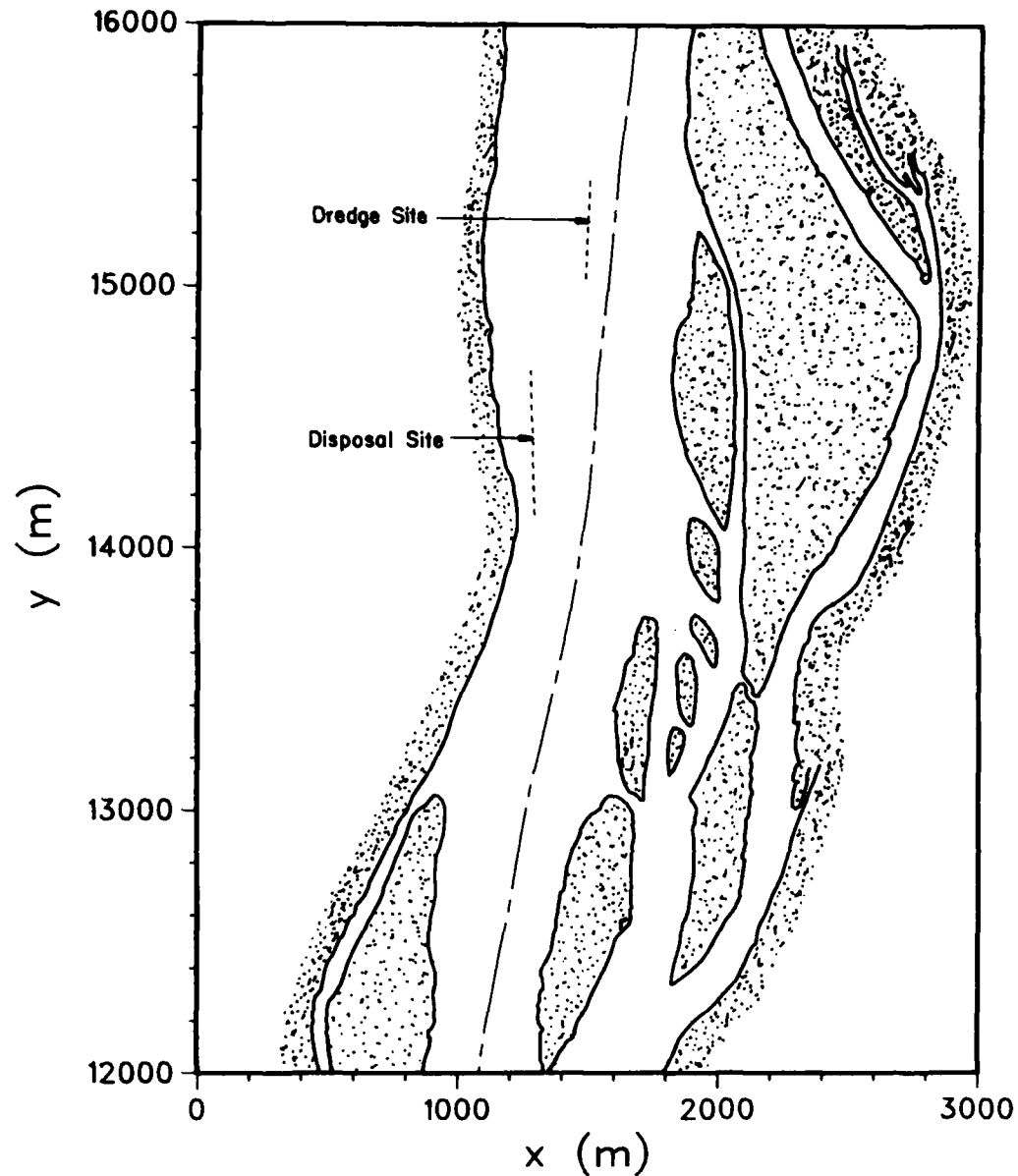
than the original area, and the contour was displaced about 0.8 km downstream from its original location. Also, the concentration of dyed sand was reduced to about 30% of that found on the initial survey. Figure 49 shows the three-dyed-sand-grain contour before and after the 1983 spring flood.

The bottom sediments in the disposal area remained predominately medium to coarse sand throughout the experiment, except for some fine sand observed during Survey I that had disappeared by Survey II.

The first five surveys at the Whitney Island site yielded no evidence of significant migration of tagged dredged sand into biologically sensitive areas such as backwaters, sloughs, or main-channel borders. Although the tagged sand migrated about 0.8 km downstream, it remained confined to the thalweg. No dyed sand was found in Stillwell Slough, even though the tagged sand moved very close to the upstream entrance of the slough during the spring 1983 flood. Instead of moving into the slough, the tagged sand followed the main channel of the river.

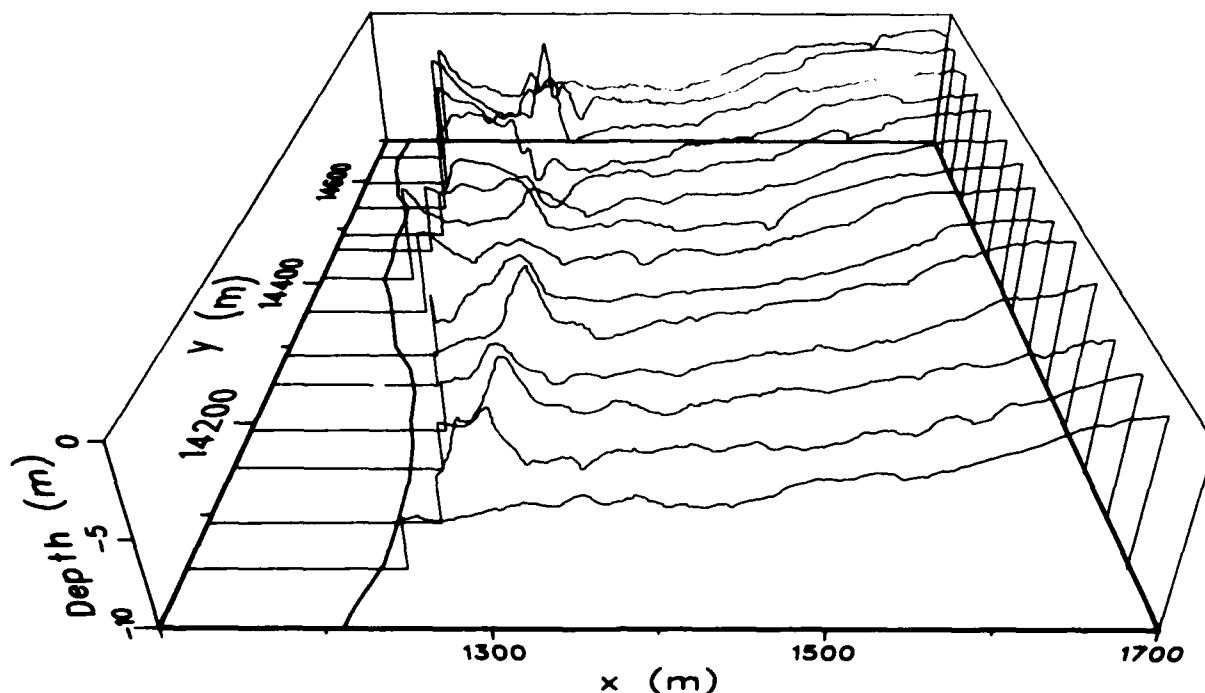
To summarize, the results from the first five surveys at the Whitney Island site indicated the following:

1. The original disposal pile, which had been quite distinct topographically, disappeared among natural bed forms after a flooding event. Following a second and more severe flood, the average bottom elevation decreased to about 0.5 m below that prior to disposal.



**FIGURE 45 Map of Whitney Island Site Showing Dredging and Disposal Areas**

2. The tagged sand, as defined by the three-dyed-sand-grain contour, migrated about 0.8 km downstream after a major flood (return period of 50 years). Virtually no dyed sand remained in the original disposal area.
3. The bottom sediments in the original disposal area remained medium to coarse sand.
4. No evidence of tagged dredged sand was found in backwaters, sloughs, or main-channel border areas.



**FIGURE 46 Perspective Plot of Transverse Bathymetric Transects for Survey I at the Whitney Island Disposal Site**

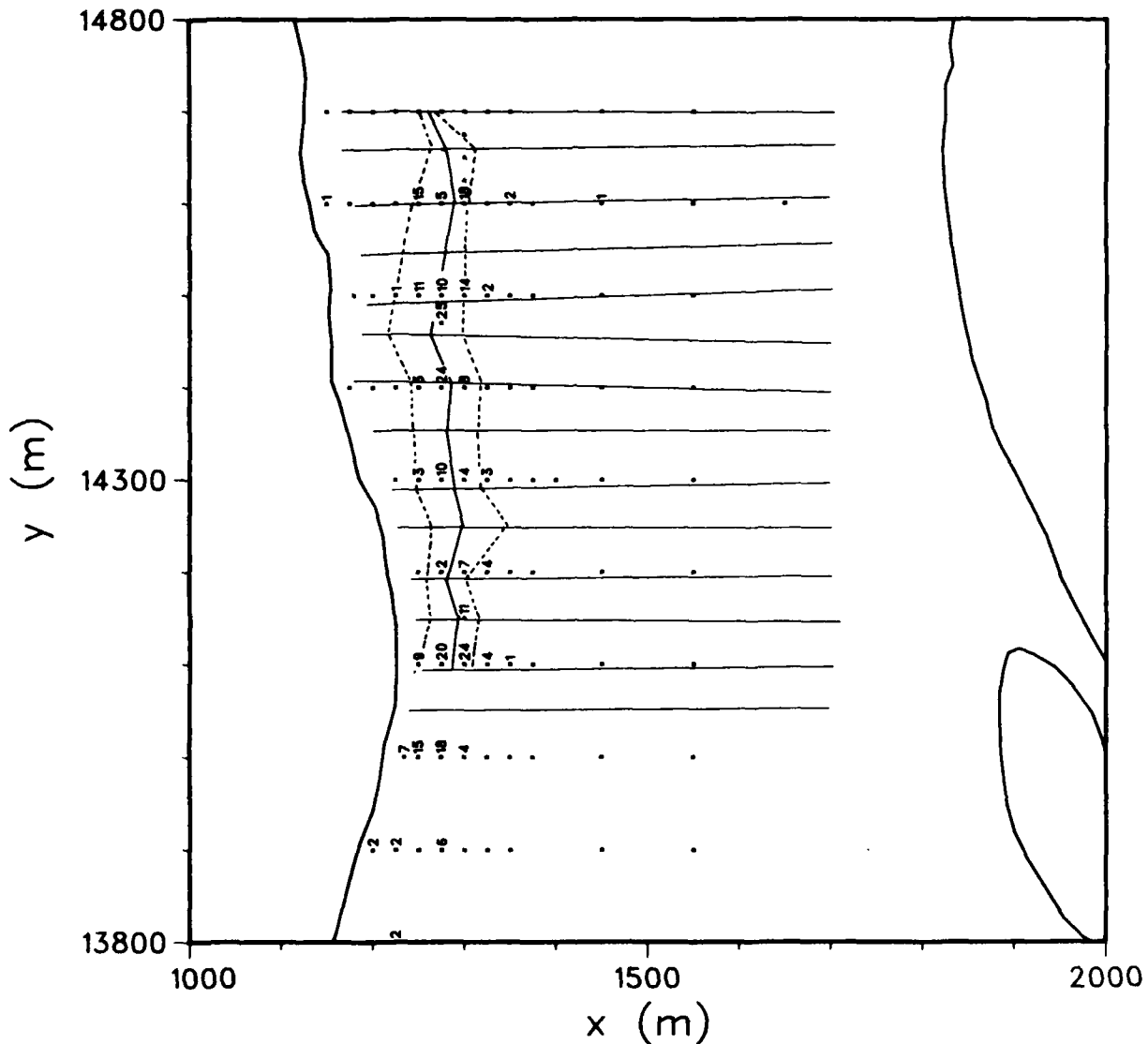
## **4.2 RESULTS OF SUBSEQUENT SURVEYS**

### **4.2.1 Results of Survey VI**

On November 30, 1983, over a year after disposal, a sixth bathymetric survey was conducted. Some of the results of the survey are presented in Fig. 50 in the form of a perspective plot; complete results are presented in Sec. B.1 of App. B. The results are similar to those of Survey V. The dunes evident in the general disposal area have a wavelength of 40-60 m and a trough-to-crest amplitude of about 2 m.

Most of the bottom sampling stations sampled during Survey VI are shown in Figs. 51 and 52. Only seven stations yielded samples having three or more dyed sand grains visible on the surface of the sample tray. Because of the low concentrations of dyed sand and the limited number of sampling stations, the area of tagged material cannot be represented by a single, simple three-dyed-sand-grain contour -- three separate contours are required. The area enclosed by the three contours appears to be about half as large as the area that existed on the previous survey. Station-by-station dyed sand results for Survey VI are presented in Sec. B.2 of App. B. For the first time, a single dyed sand grain was detected at a sampling station in Stillwell Slough.

The maximum number of dyed sand grains per station observed during Survey VI was four to five compared with six to nine during Survey V. Although this decrease appears to reflect a systematic change, the concentration of dyed sand had decreased to the point where individual differences of one or two grains are statistically insignificant.

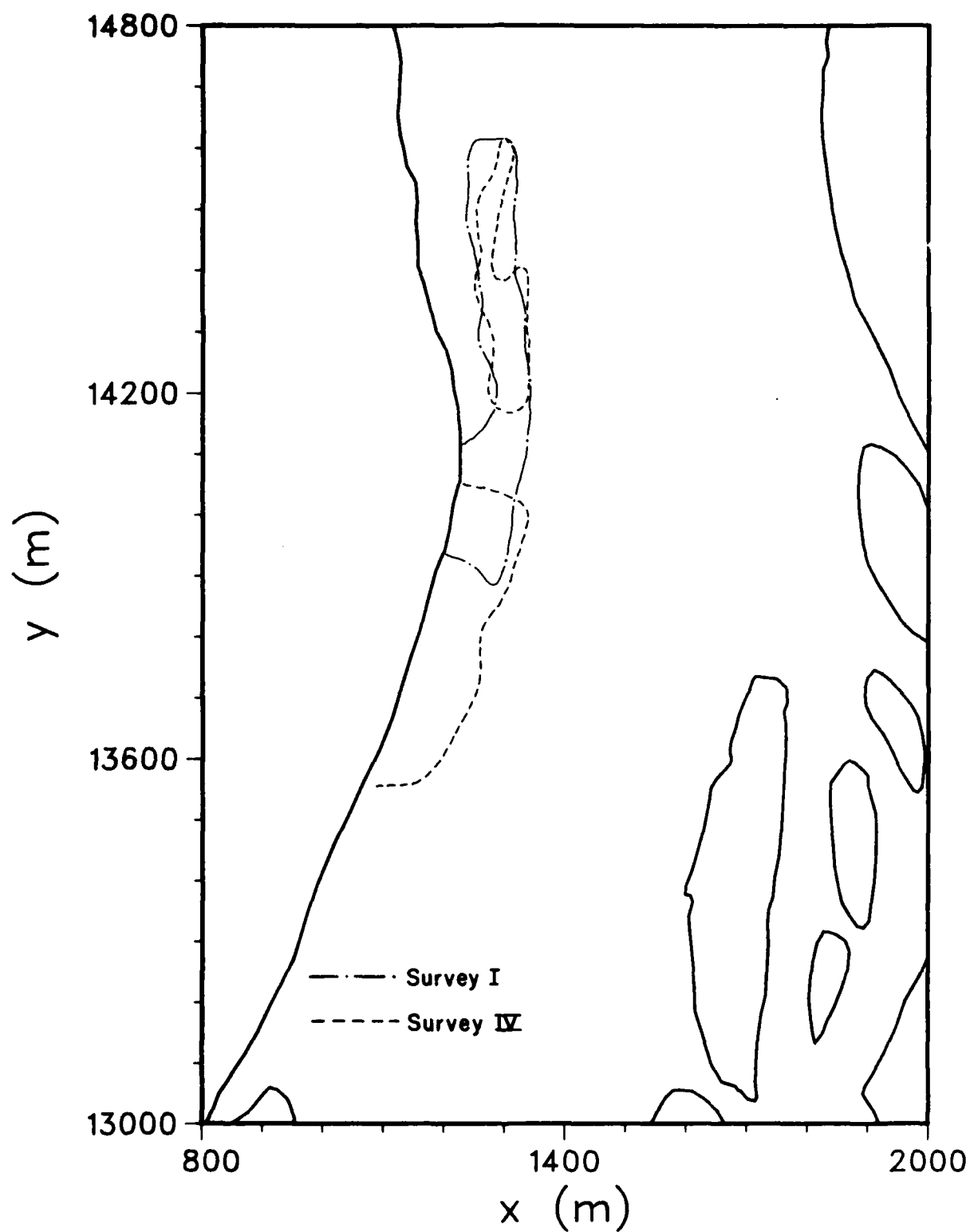


**FIGURE 47** Location of Bathymetric Transects and Bottom Sampling Stations for Survey I at the Whitney Island Disposal Site (extent of the pile and number of dyed sand grains observed are also noted)

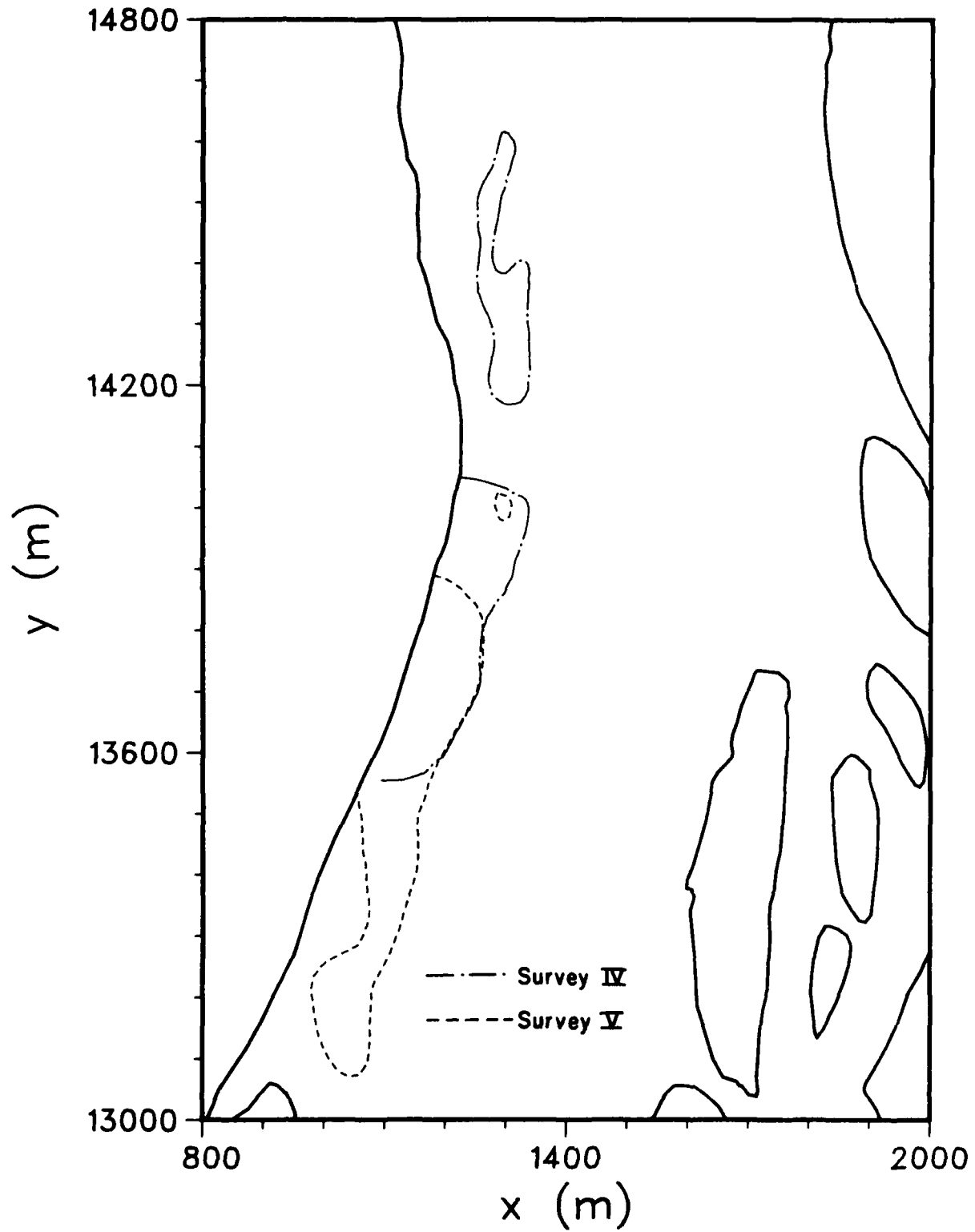
The classification of bottom sediment at the sampling station near the original disposal site is shown in Fig. 53. The key for sediment classifications used in the figure and similar figures is: Y - mud, S - silt, F - fine sand, M - medium sand, C - coarse sand, G - gravel, and R - rock. The bottom sediments remained medium to coarse sand, indicating no change in their classification since Survey V.

#### 4.2.2 Results of Survey VII

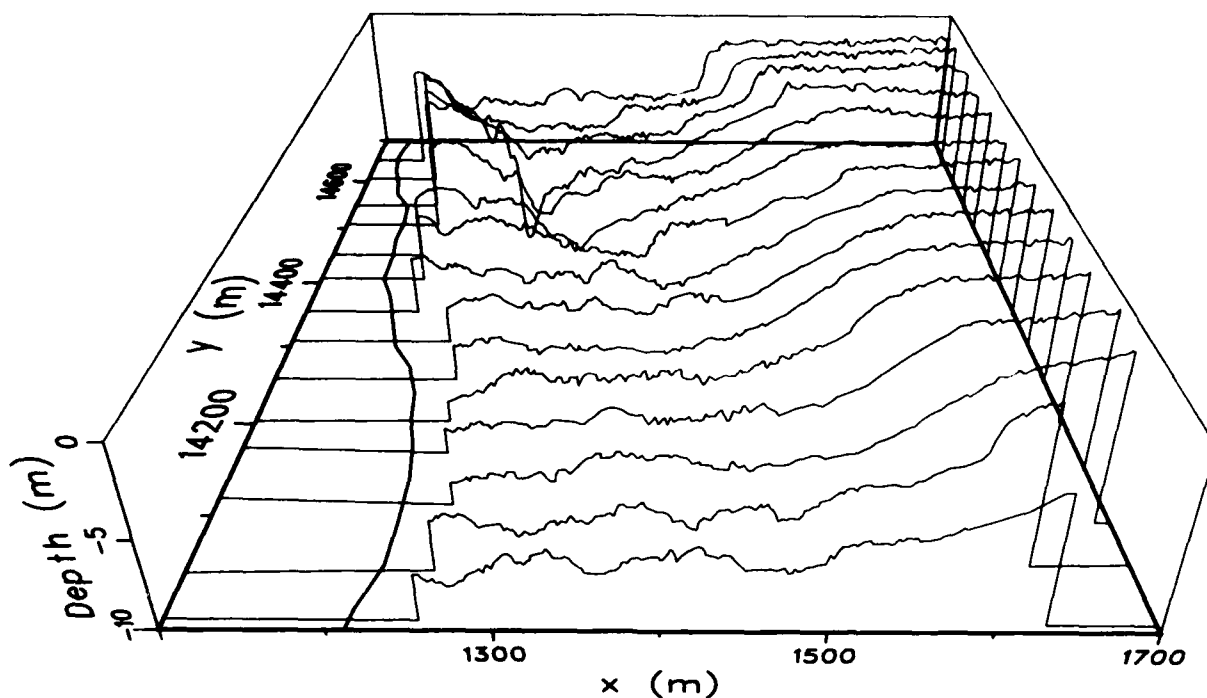
The seventh and final bathymetric survey at the Whitney Island site was conducted on October 3, 1984, about two years after the original tagging and disposal



**FIGURE 48** Distribution of Tagged Sand after Disposal and after the December 1982 Flood at the Whitney Island Disposal Site



**FIGURE 49** Distribution of Tagged Sand before and after the Spring 1983 Flood at the Whitney Island Disposal Site



**FIGURE 50 Perspective Plot of Transverse Bathymetric Transects for Survey VI at the Whitney Island Disposal Site**

operation. Because of equipment failure, data were collected from only a few of the established bathymetric transects. Some of the results from this survey are shown in Fig. 54; complete results are included in Sec. B.1 of App. B. The limited data available indicated no change in the general appearance of the bottom. Dunes were still present.

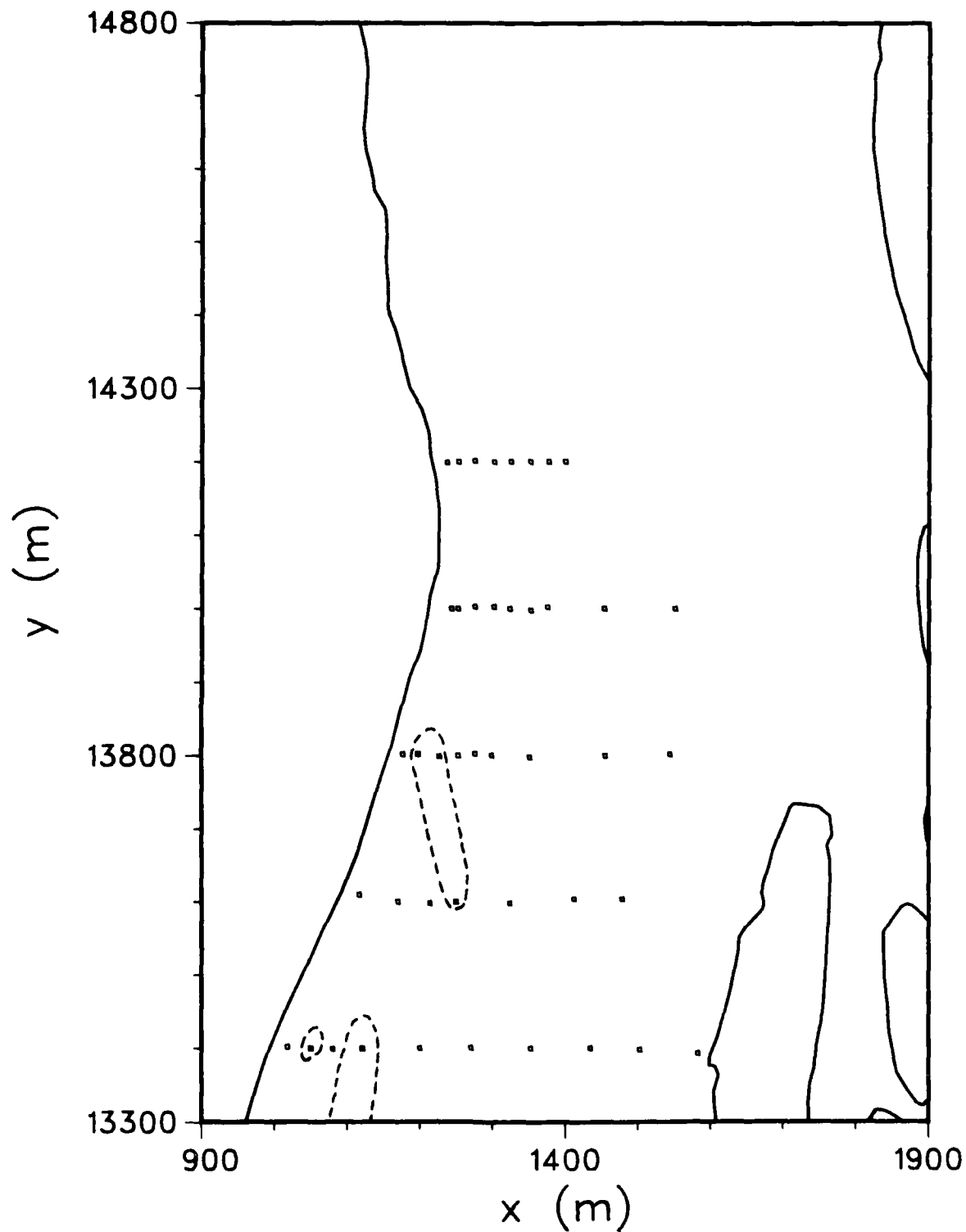
Most of the bottom sampling stations sampled during Survey VII are shown in Figs. 55 and 56. By Survey VII, only two of the 108 samples collected contained as many as three dyed sand grains. Complete results for the survey are presented in Sec. B.2 of App. B. Essentially, the tagged sand at the Whitney Island site had been so widely dispersed that it was no longer detectable by the experimental technique. The changes observed over the last few surveys indicated that the mixing and dispersion process is a very gradual one.

The general classification of the bottom sediments did not change from Survey VI to Survey VII (see Fig. 57); most of the sediments remained medium to coarse sand. No dyed sand was found in Stillwell Slough.

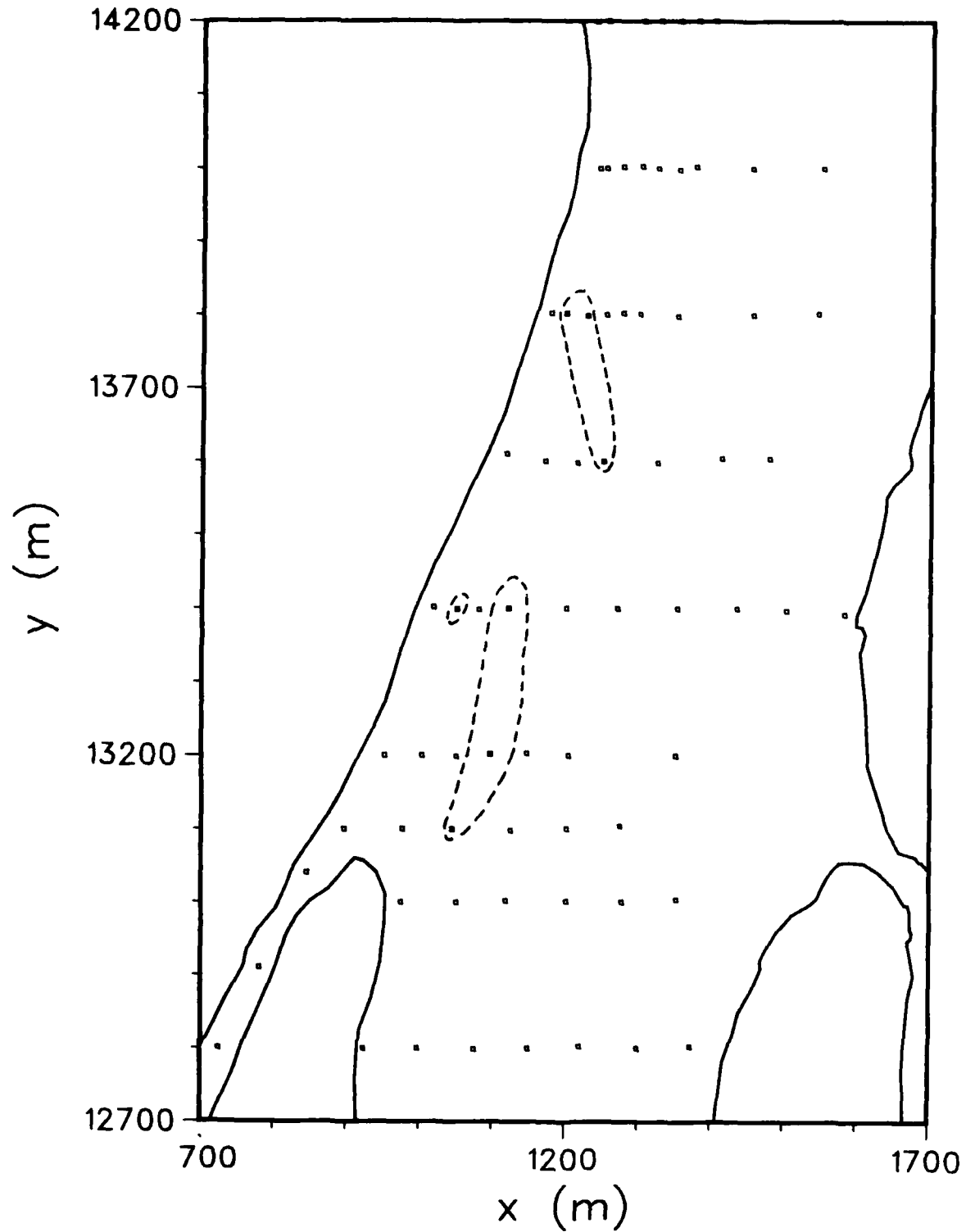
#### **4.3 SUMMARY OF WHITNEY ISLAND RESULTS**

Little change occurred at the Whitney Island site in the approximately 16 months between Surveys V and VII. This absence of change contrasts with the significant changes observed over the eight-month period between Surveys I and V, when the tagged sand moved about 0.8 km downstream in two 0.4-km steps, both steps in response to

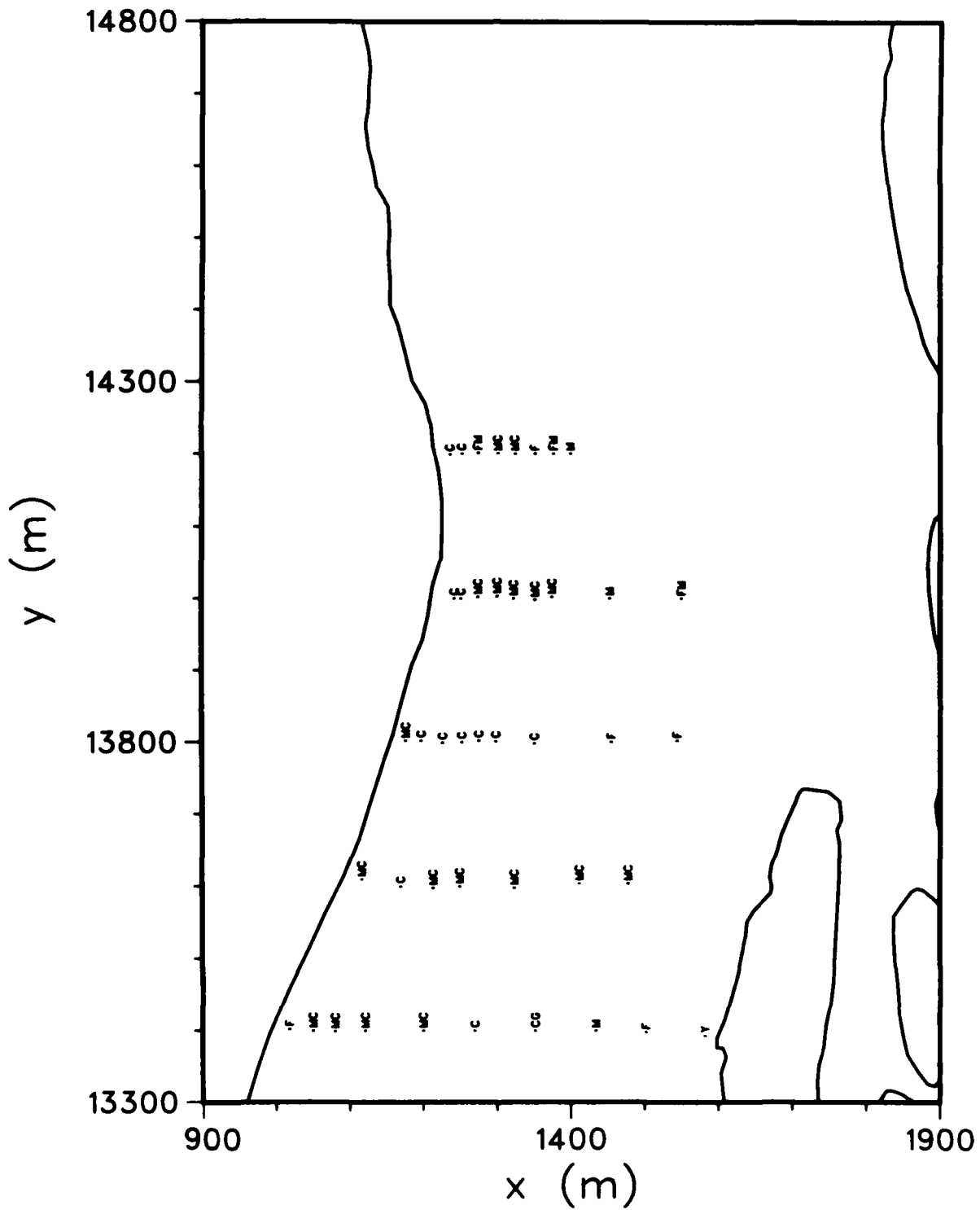




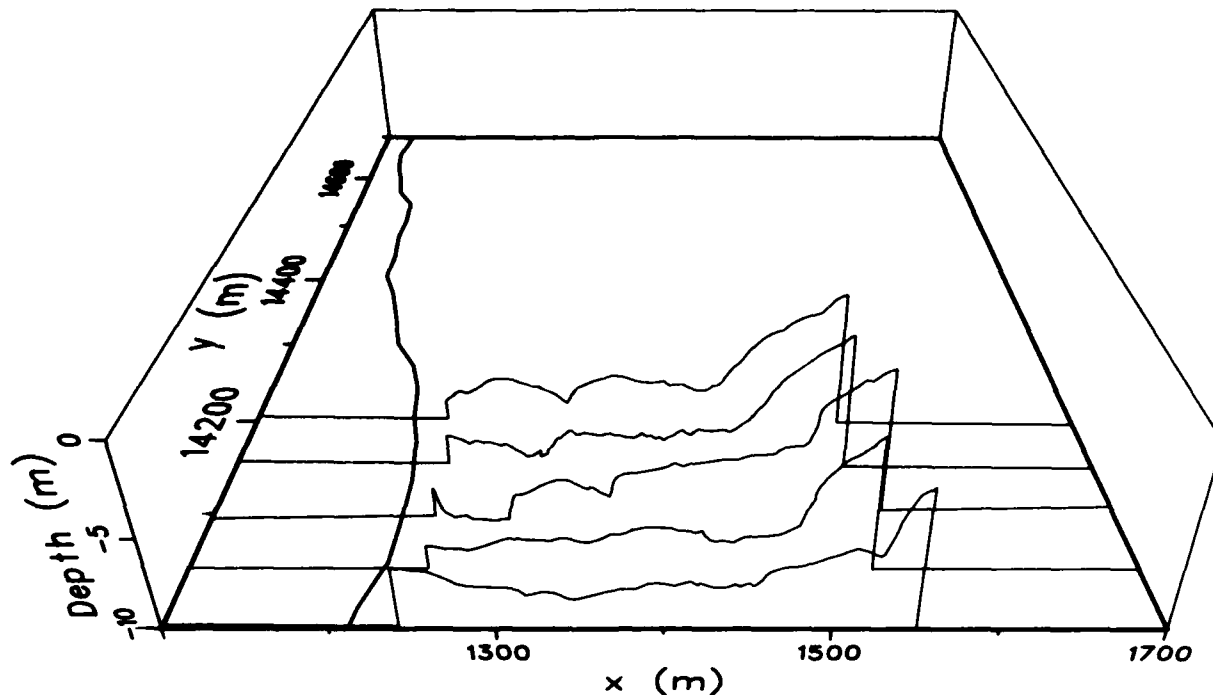
**FIGURE 51 Sampling Locations for Survey VI at the Whitney Island Disposal Site**  
(solid symbols show locations where more than three dyed sand grains were observed)



**FIGURE 52 Sampling Locations for Survey VI Downstream of the Whitney Island Disposal Site (solid symbols show locations where more than three dyed sand grains were observed)**



**FIGURE 53 Approximate Classification of Bottom Sediments at Sampling Locations for Survey VI at the Whitney Island Disposal Site**



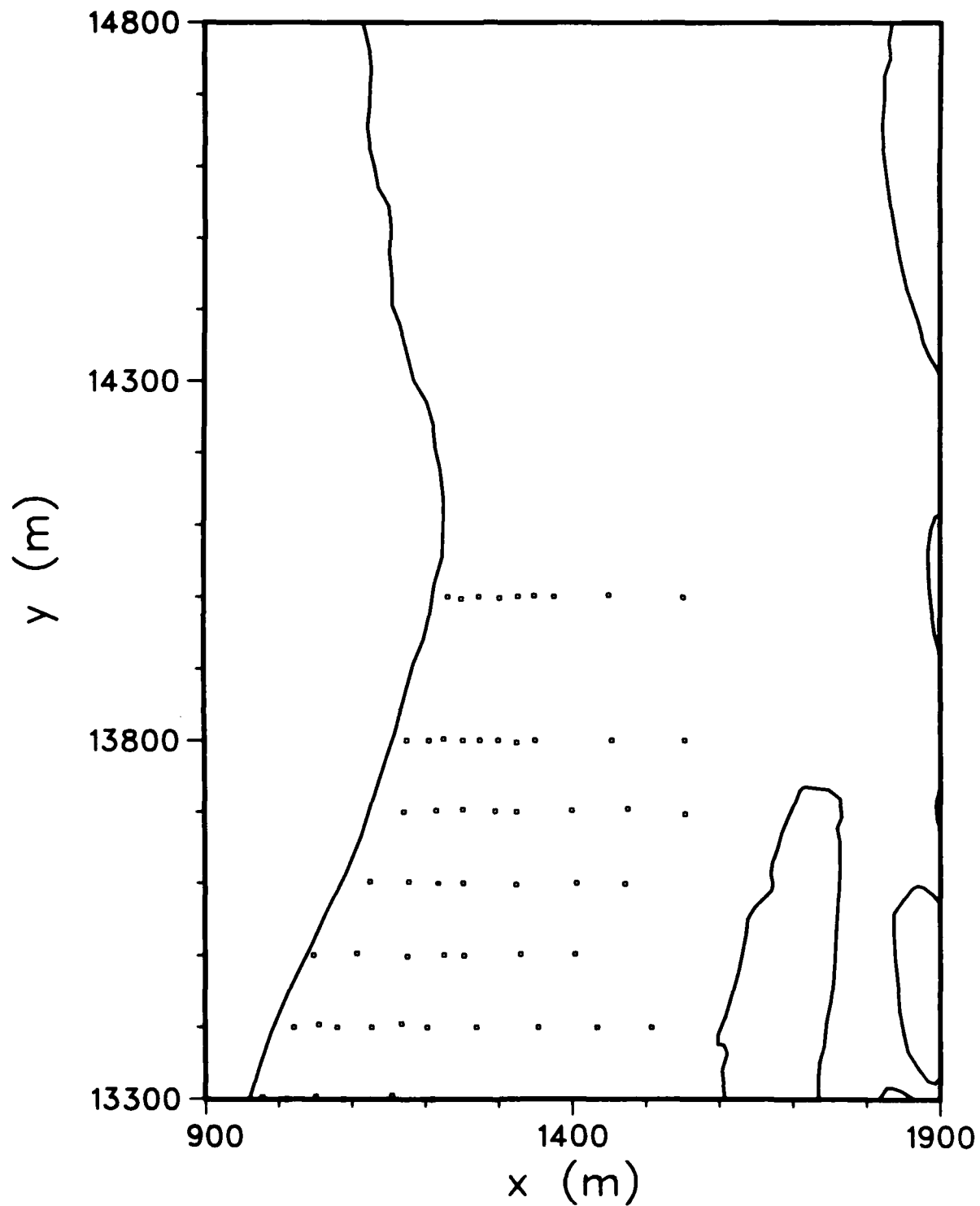
**FIGURE 54** Perspective Plot of Transverse Bathymetric Transects for Survey VII at the Whitney Island Disposal Site

periods of high river flow. In addition, the concentration of dyed sand within the three-dyed-sand-grain contour was reduced to about one-third of its initial value. In the 16 months between Surveys V and VII, no evidence was found of any further coherent movement of the dyed sand. However, the concentration of dyed sand continued to decrease until it was near or below the limits of reliable detection using the experimental technique.

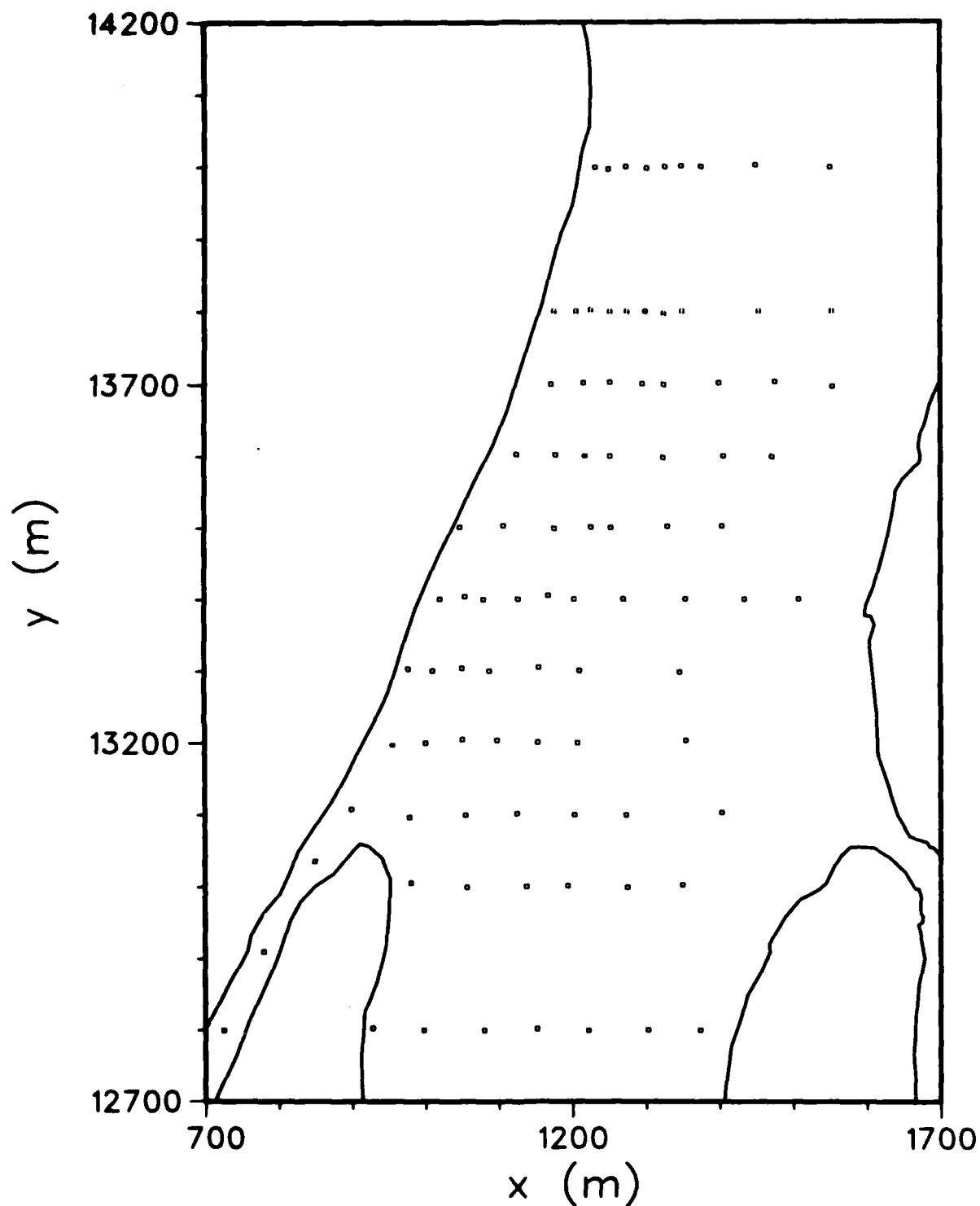
The bathymetric signature of the original disposal pile was essentially eradicated by the first major flood, which occurred in December 1982. After the following spring flood, the average bottom elevation in the disposal area was about 0.5 m below the predisposal elevation. Wavelike dune structures appeared on the bottom after the December 1982 flood. Already evident in Survey IV, the dunes have been present on each subsequent survey.

The surficial bottom sediments in the disposal area are predominately medium to coarse sand. However, on the first survey after the disposal operation (Survey I), some fine sand was present in the disposal area. This fine sand disappeared by Survey II, and the bottom sediments remained medium to coarse sand thereafter.

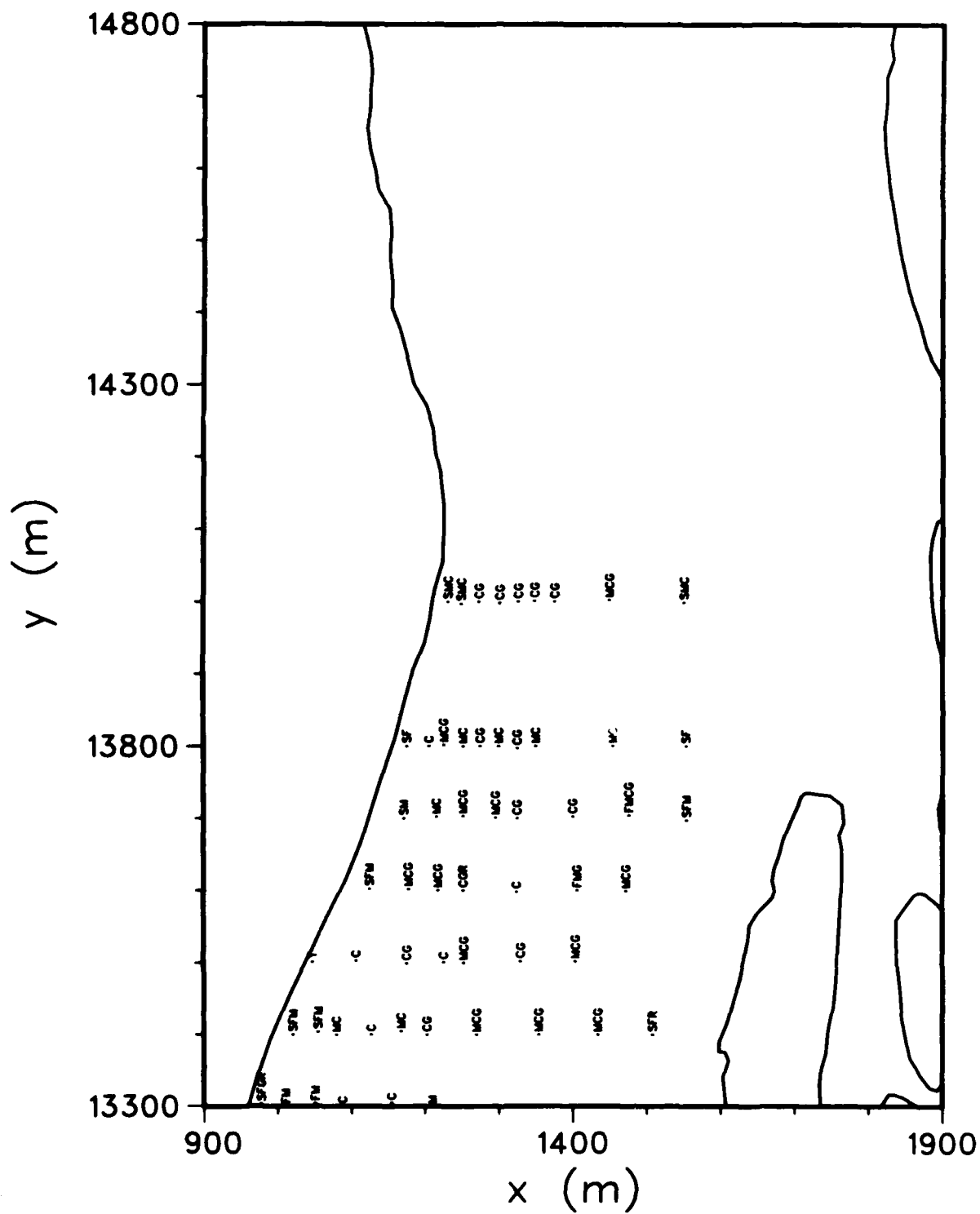
At the Whitney Island site, as well as at the Gordon's Ferry and Savanna Bay sites, no evidence was found of any significant migration of tagged dredged sand into biologically sensitive areas such as backwaters, sloughs, or main-channel borders. Although the tagged sand migrated about 0.8 km downstream at the Whitney Island site, it remained in the thalweg. Throughout the experiments at the site, only one dyed sand



**FIGURE 55 Sampling Locations for Survey VII at the Whitney Island Disposal Site**  
(solid symbols show locations where more than three dyed sand grains were observed)



**FIGURE 56 Sampling Locations for Survey VII Downstream of the Whitney Island Disposal Site (solid symbols show locations where more than three dyed sand grains were observed)**



**FIGURE 57 Approximate Classification of Bottom Sediments at Sampling Locations for Survey VII at the Whitney Island Disposal Site**

grain was ever found in samples collected in Stillwell Slough (Survey VI), even though the tagged sand moved very close to the upstream entrance of the slough during the high river flows that occurred in the spring of 1983. Instead of moving into the slough, the tagged sand followed the main channel of the river.

Results from the seven surveys at the Whitney Island site can be summarized as follows:

1. The original disposal pile, which was quite distinct topographically, disappeared among natural bed forms after a flooding event. Following a second and more severe flood, the average bottom elevation was about 0.5 m below what it had been prior to disposal.
2. The tagged sand, as defined by the three-dyed-sand-grain contour, migrated about 0.8 km downstream after a flooding event with a 50-year return period. Virtually no dyed sand remained in the original disposal area. No further movement of the three-dyed-sand-grain contour occurred. However, the concentration of dyed sand decreased until it could no longer be reliably detected by the experimental technique.
3. The bottom sediments in the original disposal area remained medium to coarse sand.
4. No evidence was found of large-scale migration of tagged dredged material into backwaters, sloughs, or main-channel border areas.



## 5 SUMMARY AND CONCLUSIONS

Argonne conducted three large-scale field experiments on the Upper Mississippi River to measure the movement of dredged sand, which had been tagged with dyed sand and returned to a deeper reach of the main channel downstream of the dredging site. The tagged dredged sand initially formed a pile along the thalweg of the river. Bathymetric surveys and bottom sediment samples were used to determine changes in the disposal pile and the downstream distribution of the tagged dredged sand. The results of these studies have been reported in a three-volume report (ANL/EES-TM-270), of which this volume is the third.

The first full-scale experiment was initiated in the fall of 1981 during routine dredging at the Gordon's Ferry site. Experience gained at this site was used to refine the experimental procedures, and a second experiment was initiated at the Whitney Island site in the fall of 1982. The experimental procedures and the results from surveys at these first two sites through June 1983 are discussed in ANL/EES-TM-270, Vol. 1.<sup>1</sup>

The third experiment using a dyed sand tracer was initiated at the Savanna Bay site in the fall of 1983. In addition, bathymetric measurements were carried out at a fourth thalweg disposal site (Duck Creek) near the Savanna Bay site to monitor changes in the physical structure of the disposal pile. Dyed sand was not used at the Duck Creek site. The results from surveys at these second two sites over a nine-month period are presented in ANL/EES-TM-270, Vol. 2.<sup>2</sup>

Results from additional surveys at the Gordon's Ferry and Whitney Island sites through the fall of 1984, including results from the analysis of bottom cores collected at the Gordon's Ferry site during the summer of 1983, are reported in this volume (ANL/EES-TM-270, Vol. 3). Detailed summaries of site-specific results for the Gordon's Ferry and Whitney Island sites are given in Secs. 3.4 and 4.3. Section 5 includes some general observations based on the results from all the experimental sites.

The experiments have clearly demonstrated the feasibility of conducting large-scale thalweg disposal experiments with tagged dredged sand. No significant logistical or operational problems arose with regard to dyeing large amounts of river sand and injecting it into the dredged sand prior to disposal during routine dredging. Sampling for and detecting dyed sand in the surficial bottom sediments of the river were accomplished with relative ease. The precision navigation and onboard plotting system provided the flexibility to adjust to changing conditions in the field and allowed efficient and reliable repetitive sampling. Minor improvements in the sampling technique during the progress of the experiments increased the rate at which bottom samples could be collected and photographed. During the first few surveys, about 35-40 samples per day could be collected under good conditions (i.e., low river flow, low winds, and no ice). This rate increased to 75-80 samples per day in the later surveys.

The general behavior of the dredged sand deposited as a pile in the thalweg was similar at all the experimental sites. The bathymetric surveys in the area of the disposal pile revealed that the pile remained as a distinguishable topographic feature until the first period of high river flow. Sand dunes then developed in the area. The dunes

remained at those sites where dunes were a normal feature of the bottom topography. However, at the Duck Creek site, where the bottom was originally rocky and fairly flat, the dune structure disappeared and the bottom returned to its original condition within a year's time.

The distribution of dyed sand in the surficial bottom sediments, as determined by the bottom sampling surveys, showed that the tagged dredged sand moved downstream along the thalweg in a fairly coherent patch. The movement of the patch generally could be correlated with river discharge and therefore probably with river currents. At the Gordon's Ferry and Whitney Island sites, the patch moved or elongated primarily in response to periods of high river discharge. At the Savanna Bay site, the patch moved even during periods when flows were not particularly high. This site-specific difference can probably be attributed to the narrowness of the river at the Savanna Bay site, which results in currents that are locally faster than at the Gordon's Ferry and Whitney Island sites.

The results from the coring experiment at the Gordon's Ferry site indicated that virtually all of the tagged sand remaining as a coherent patch in the thalweg resides within the dunes along the river bottom. Almost no dyed sand was found in the bottom sediments at depths below the troughs of the local dune structure. Much of the original dredged sand that was deposited as a pile along the thalweg has apparently become incorporated into the dunes and is migrating downstream within the dune system.

At the three sites where dyed sand was used to tag the dredged sand, surficial bottom sediments were extensively sampled downstream of the disposal site and in potentially sensitive areas (e.g., main-channel borders, backwaters, and sloughs). No evidence was found of coherent movement of dredged sand out of the thalweg into these areas.

The original objective of these experiments was to determine the location and movement of dredged sand disposed of as a pile in the thalweg of the Upper Mississippi River. The detailed behavior of dredged sand at a specific site will clearly depend on the particular disposal configuration, the local river geometry and bottom topography, and subsequent river flow conditions. However, it can be concluded from these experiments that the sand will generally be incorporated into the local dune structure and migrate downstream in the thalweg with the dunes.

## REFERENCES

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9. Pettijohn, F.J., *Sedimentary Rocks*, 2nd Ed., Harper and Row, New York (1957).

**APPENDIX A**  
**GORDON'S FERRY — DETAILED DATA**

## APPENDIX A

### GORDON'S FERRY — DETAILED DATA

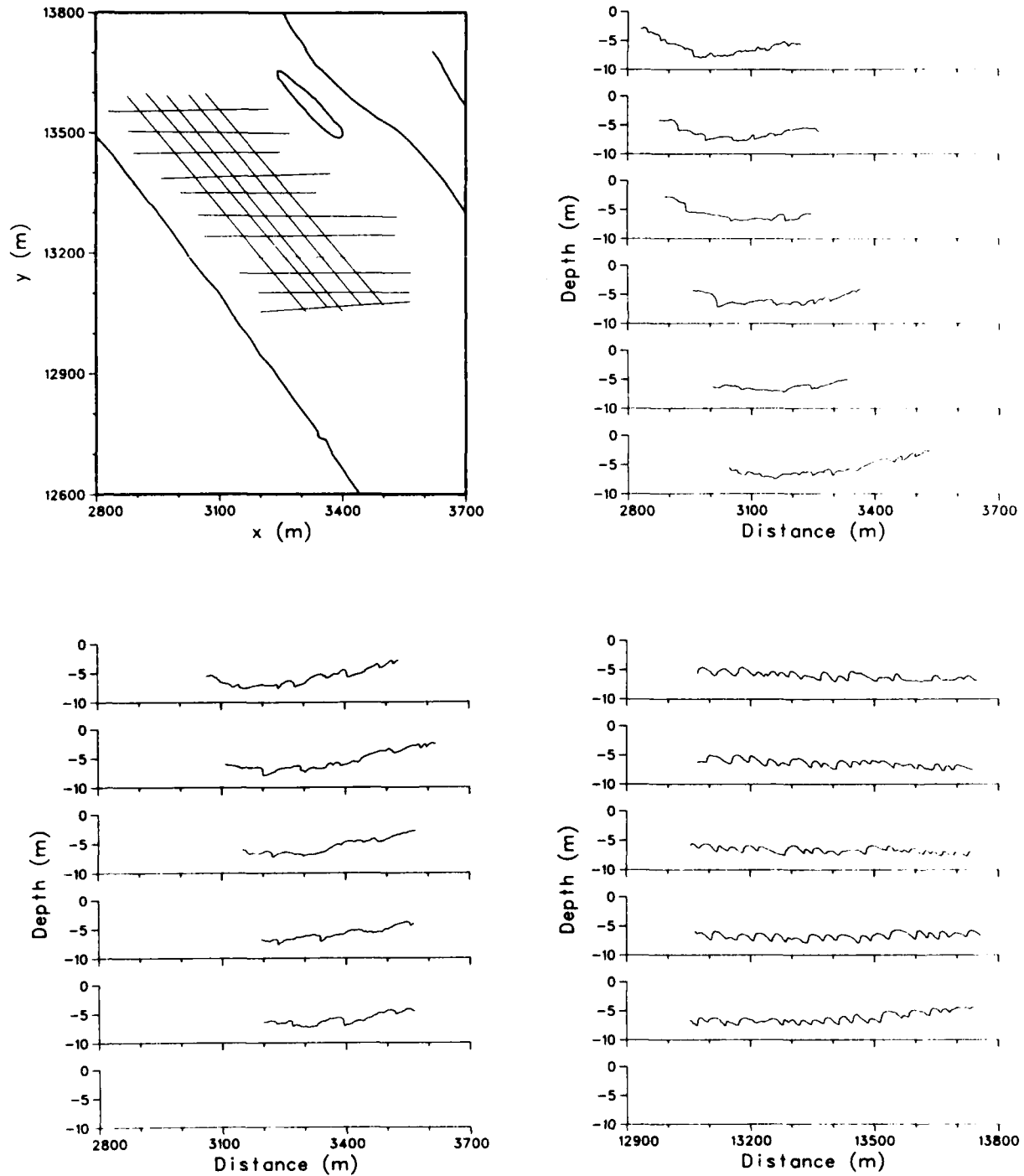
The results and some of the data from Surveys VIII and IX at the Gordon's Ferry site are presented and discussed in Sec. 3. The complete sets of bathymetric data and dyed sand data from each of these surveys are given in this appendix.

#### A.1 BATHYMETRIC DATA FROM THE GORDON'S FERRY DISPOSAL SITE

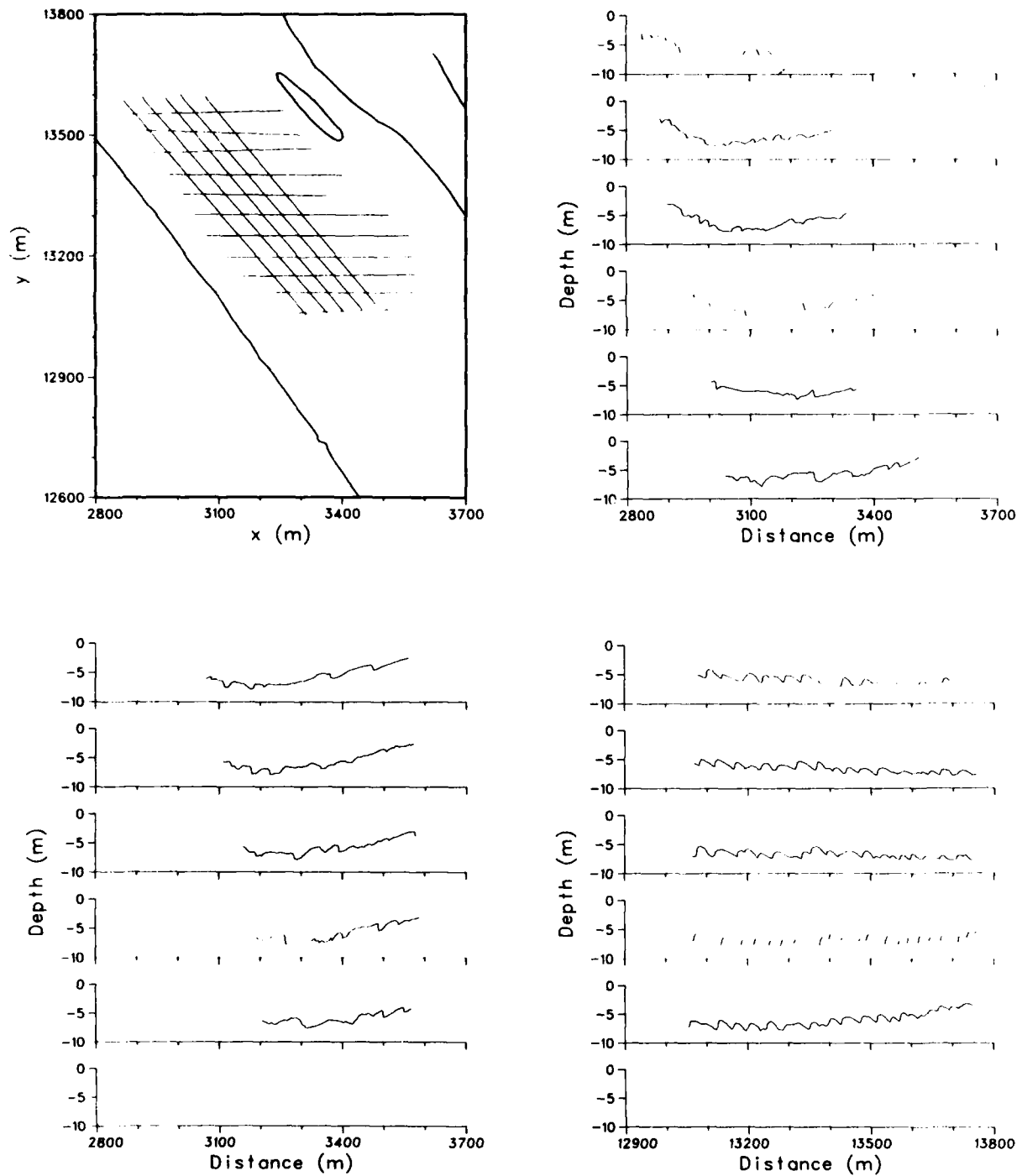
The complete bathymetric data from Surveys VIII and IX at Gordon's Ferry are presented in Figs. A.1 and A.2. The approximate boat paths for each set of transects are shown in the upper left-hand quadrant of each figure. The bottom profiles for the transverse transects (approximately parallel to the x axis) are presented in sequence, starting in the upper right-hand quadrant with the transect farthest upstream (northernmost) and proceeding downstream (southward). The profiles for the individual transects are plotted, starting from the Iowa (west) end of each transect. The bottom profiles for the longitudinal transects (approximately parallel to the original disposal pile) are then presented in sequence, starting with the transect closest to the Illinois (east) shore and proceeding toward the Iowa (west) shore. The profiles for the individual transects are plotted, starting from the downstream end of each transect.

#### A.2 DYED SAND DATA FROM THE GORDON'S FERRY DISPOSAL SITE

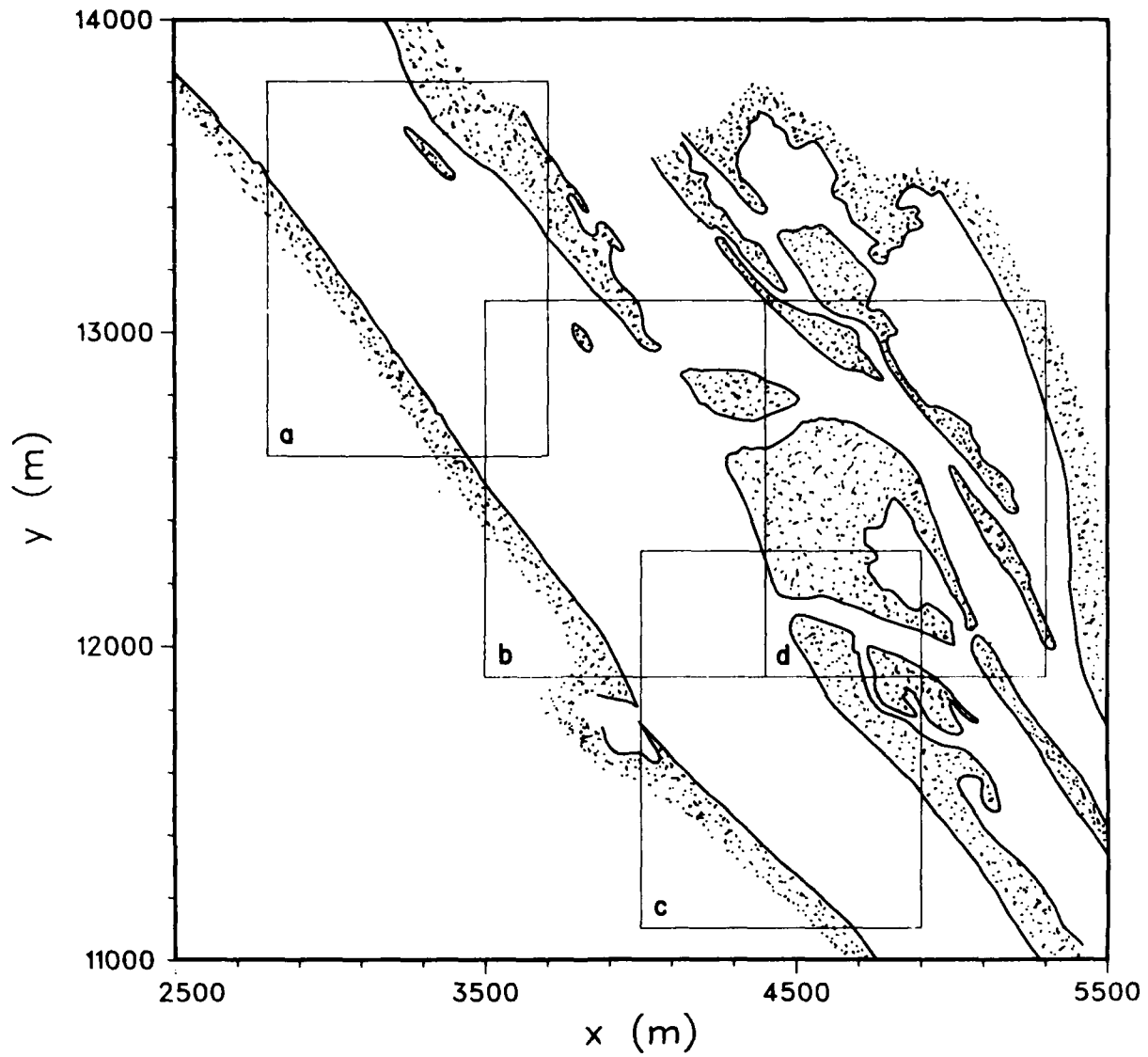
For presentation purposes, the study area was divided into four regions (a, b, c, and d) as shown in Fig. A.3. Region a encompasses the original disposal area, and Region b includes the two principal entrances to Stone Slough and the nearby main-channel area. Region c covers the area downstream of the slough entrances, and Region d covers the upstream portion of Stone Slough. The sampling locations for Surveys VIII and IX are shown in Figs. A.4-A.11. The number of individual dyed sand grains, if any, observed in the photographs of the surface of the 23 x 23 cm sample tray illuminated by ultraviolet light is given adjacent to each sampling location.



**FIGURE A.1 Bathymetric Transects and Transverse and Longitudinal Bottom Profiles for Survey VIII at Gordon's Ferry on September 1, 1983**

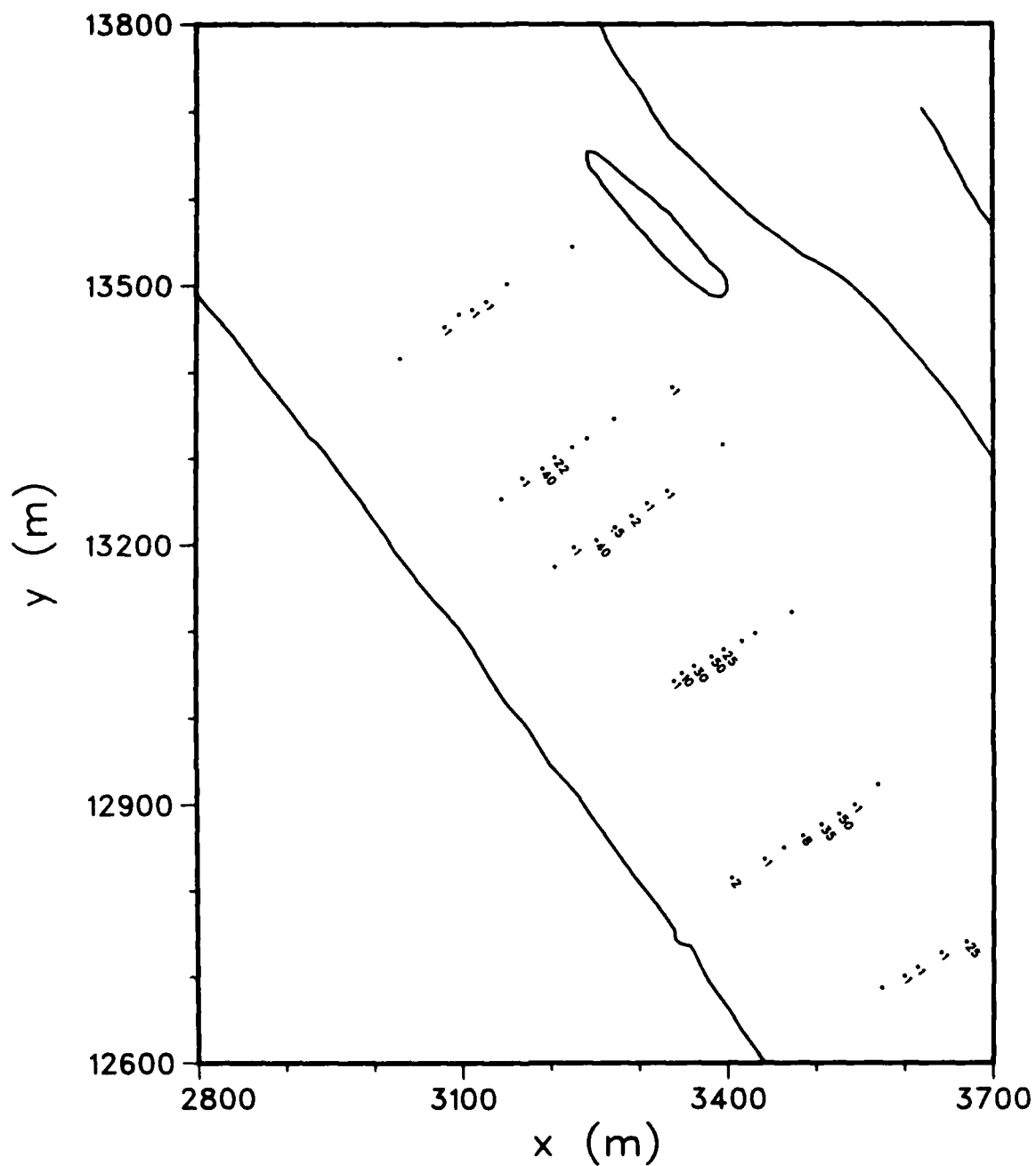


**FIGURE A.2 Bathymetric Transects and Transverse and Longitudinal Bottom Profiles for Survey IX at Gordon's Ferry on September 20, 1984**

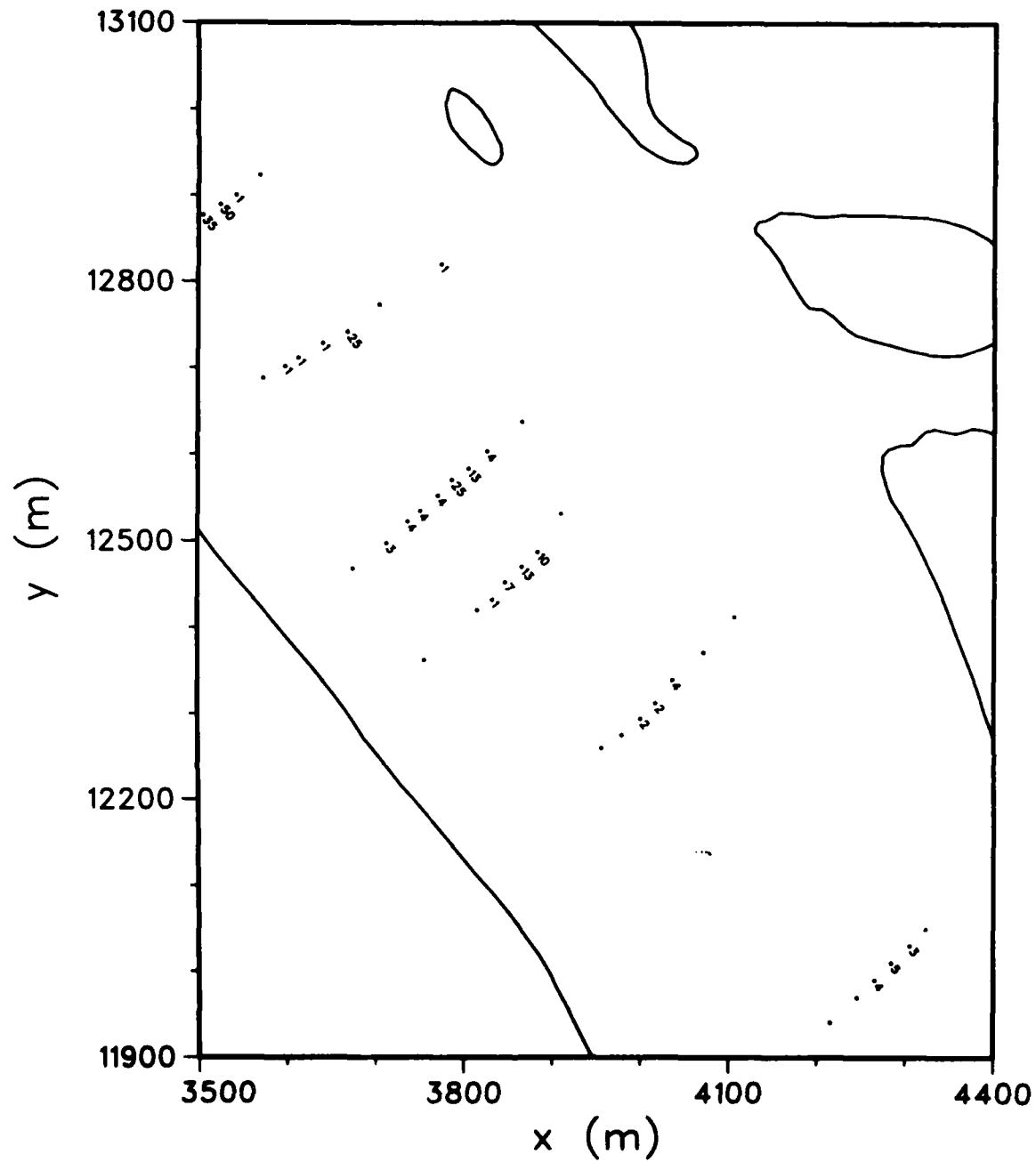


**FIGURE A.3** Gordon's Ferry Site Showing the Four Regions (a, b, c, and d) where Bottom Samples Were Obtained

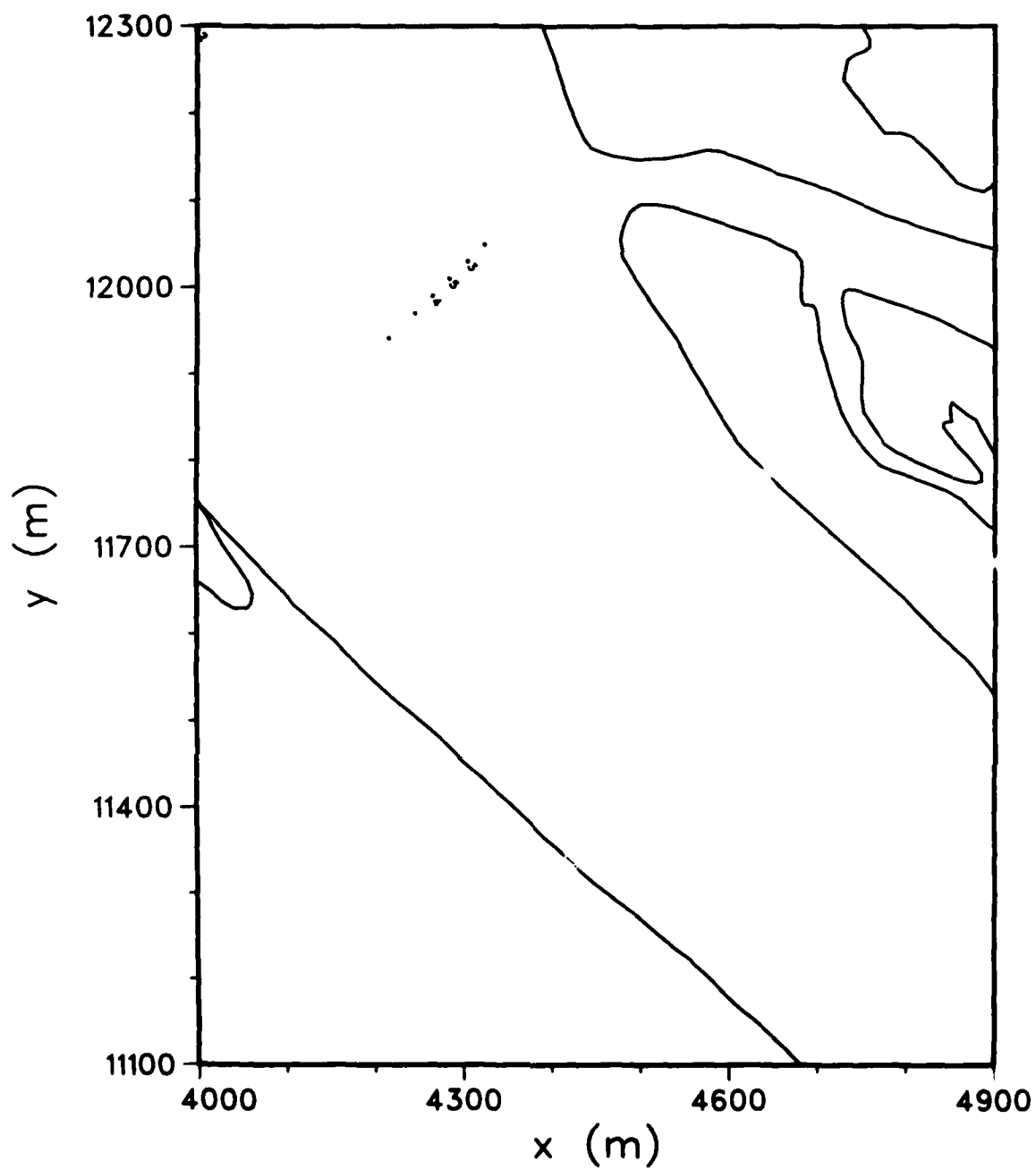




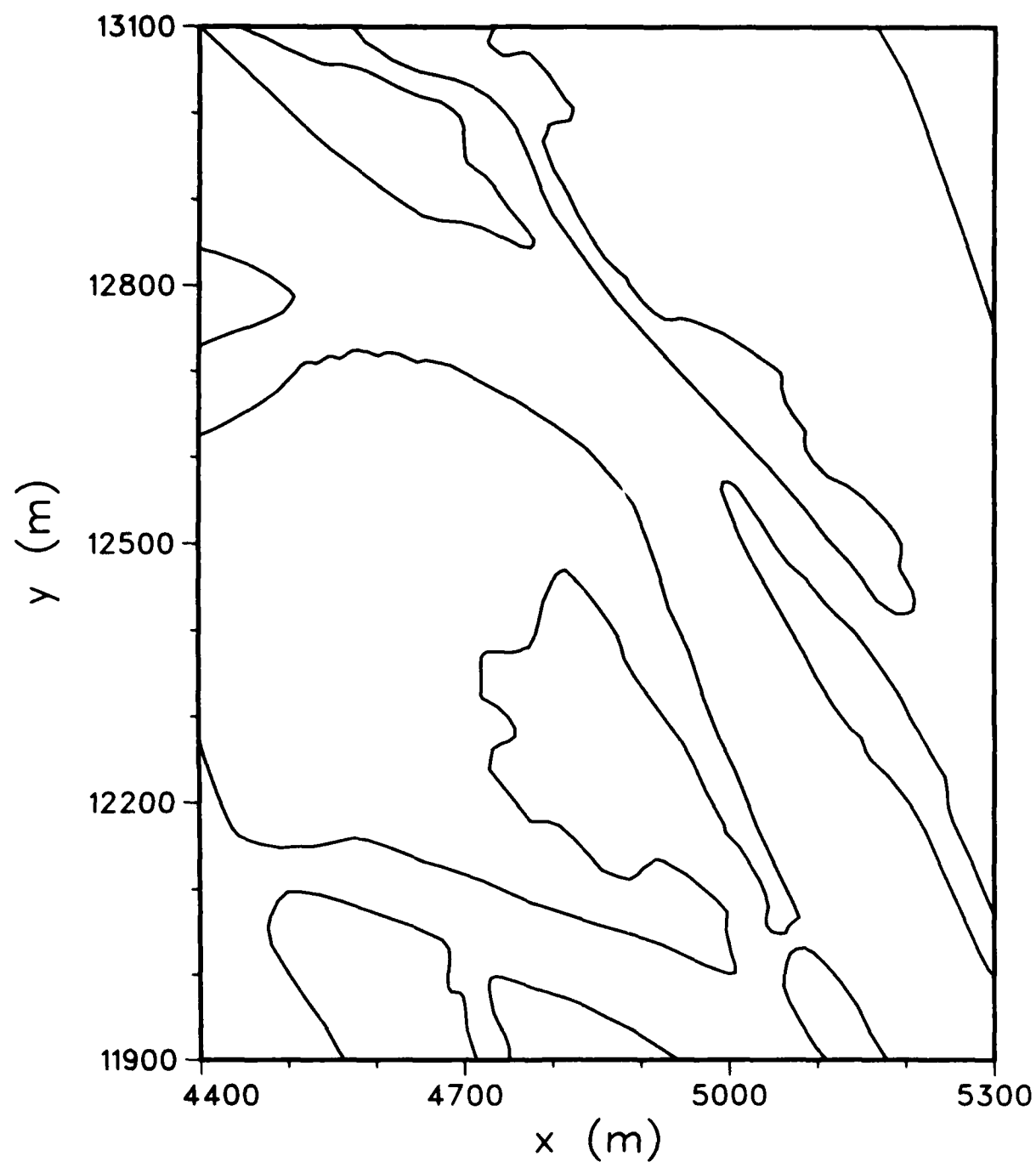
**FIGURE A.4 Bottom Sampling Locations and Dyed Sand Counts in Region a of the Gordon's Ferry Site for Survey VIII**



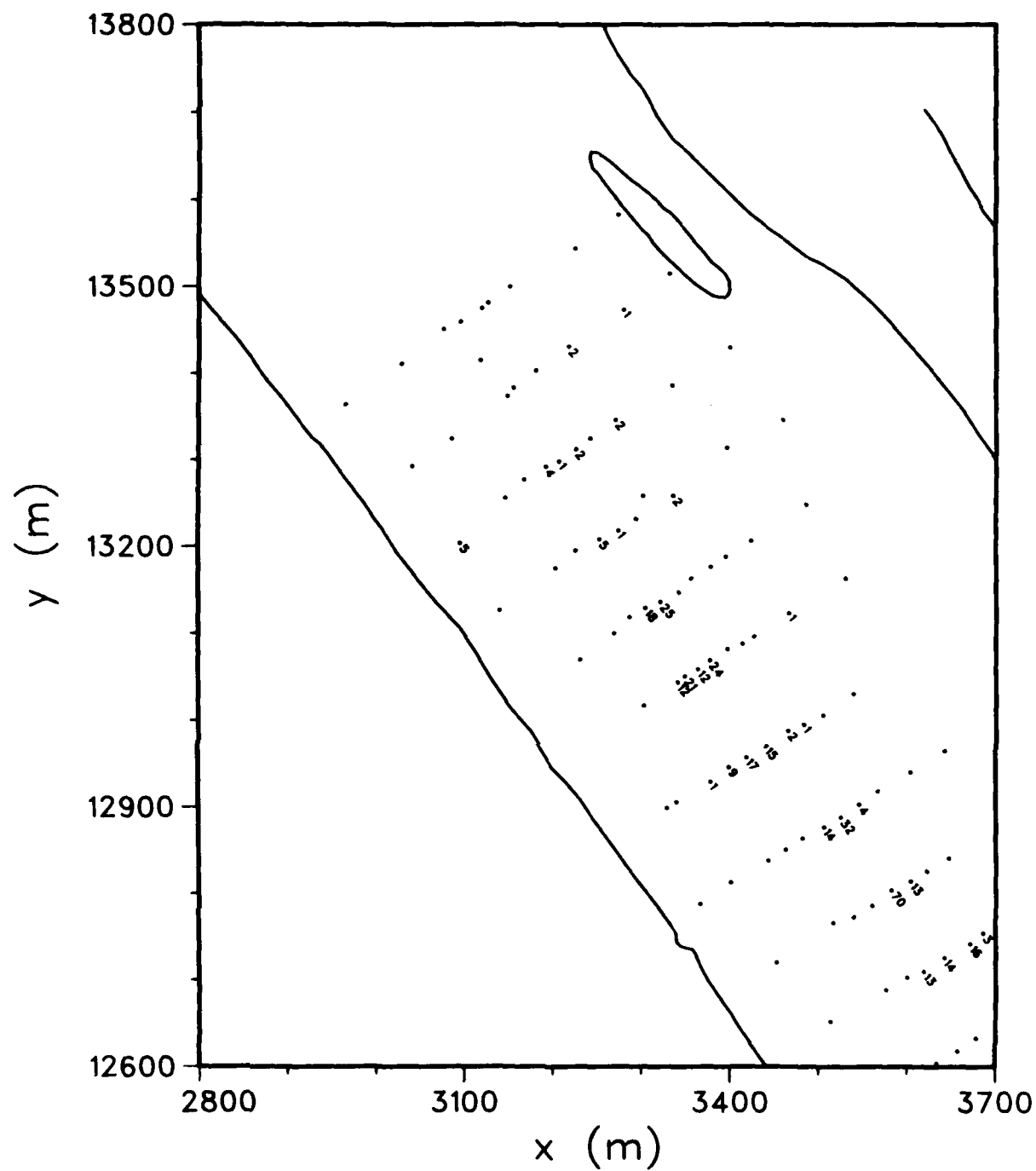
**FIGURE A.5** Bottom Sampling Locations and Dyed Sand Counts in Region b of the GorJon's Ferry Site for Survey VIII



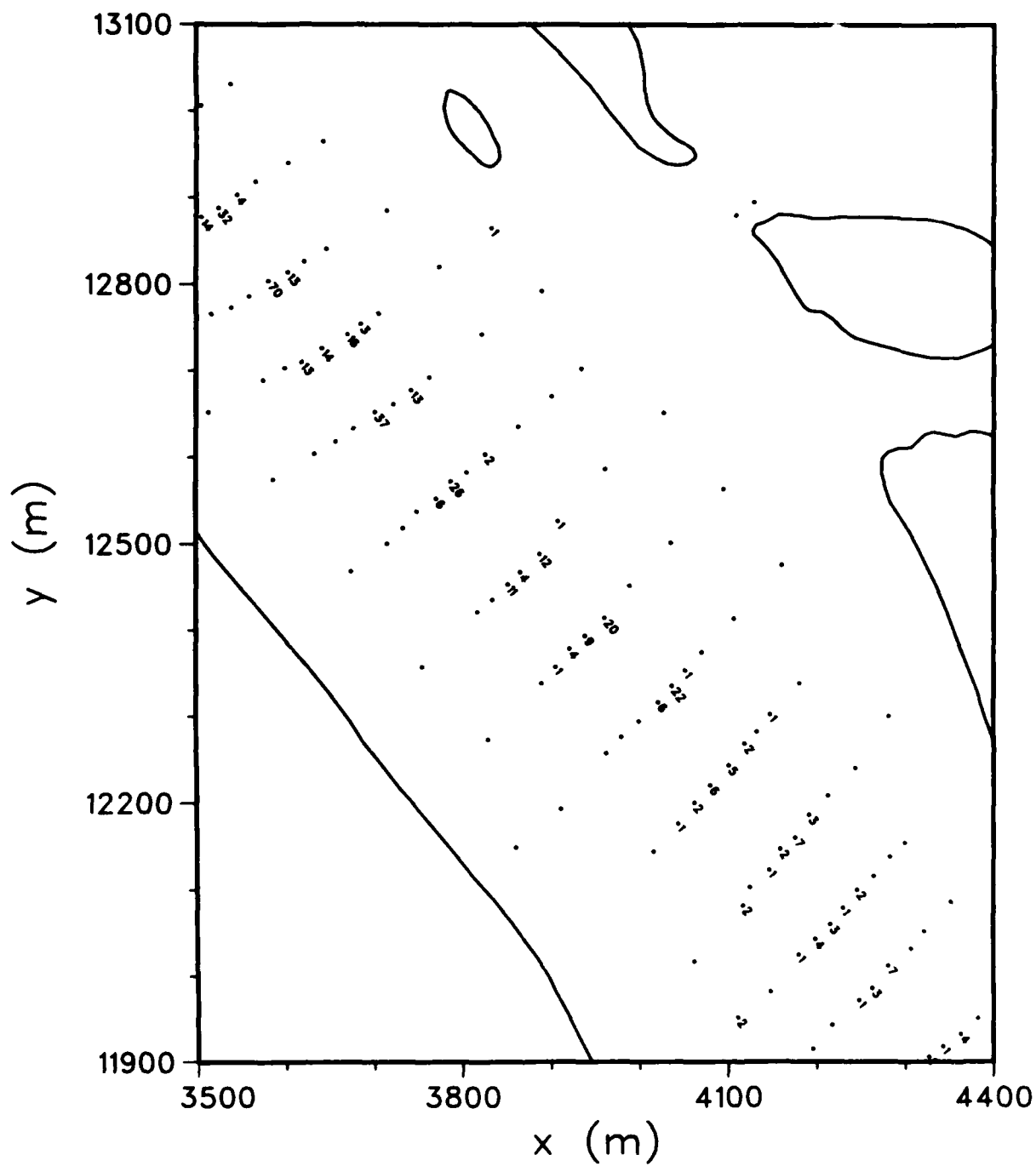
**FIGURE A.6 Bottom Sampling Locations and Dyed Sand Counts in Region c of the Gordon's Ferry Site for Survey VIII**



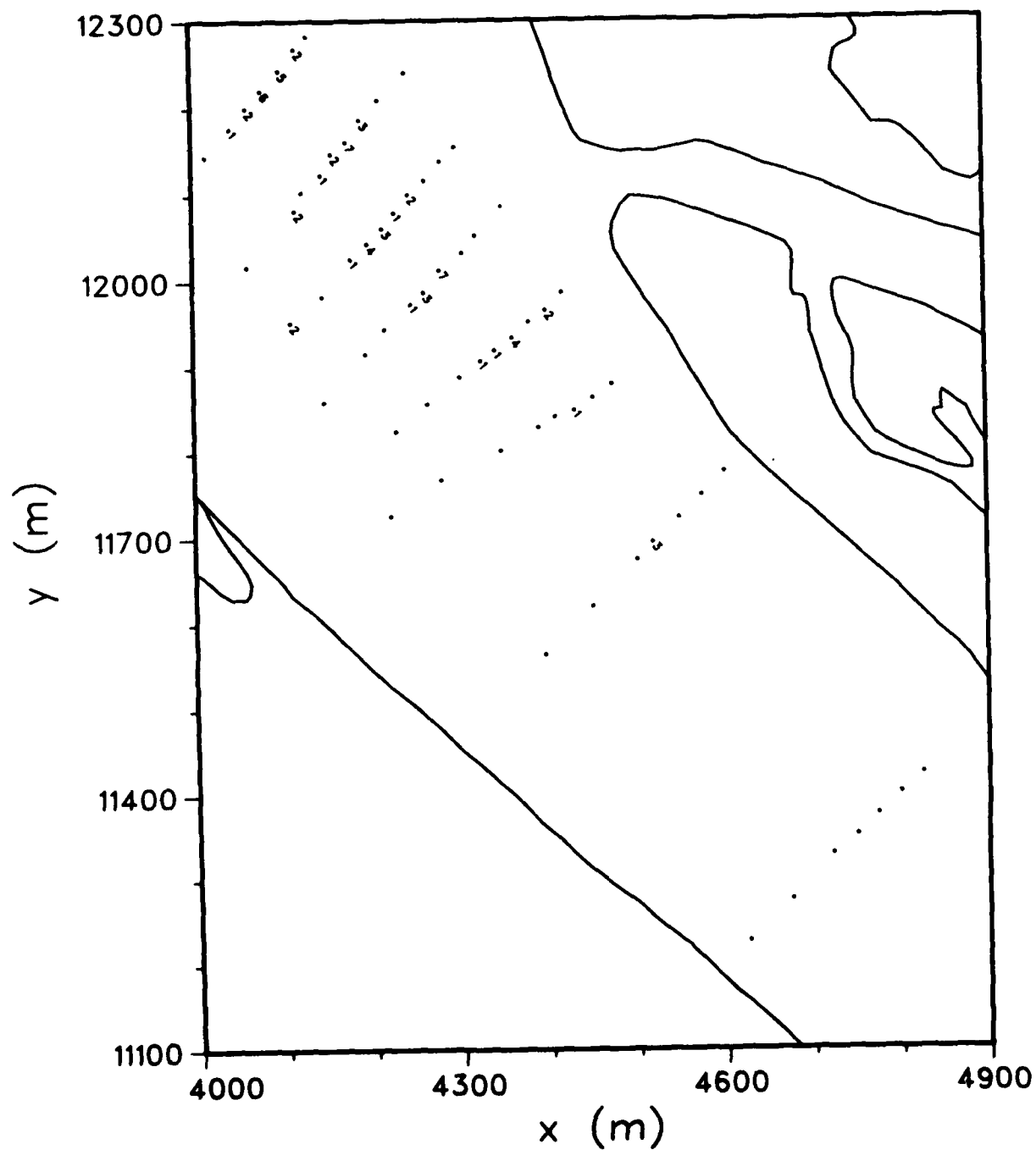
**FIGURE A.7 Bottom Sampling Locations and Dyed Sand Counts in Region d of the Gordon's Ferry Site for Survey VIII**



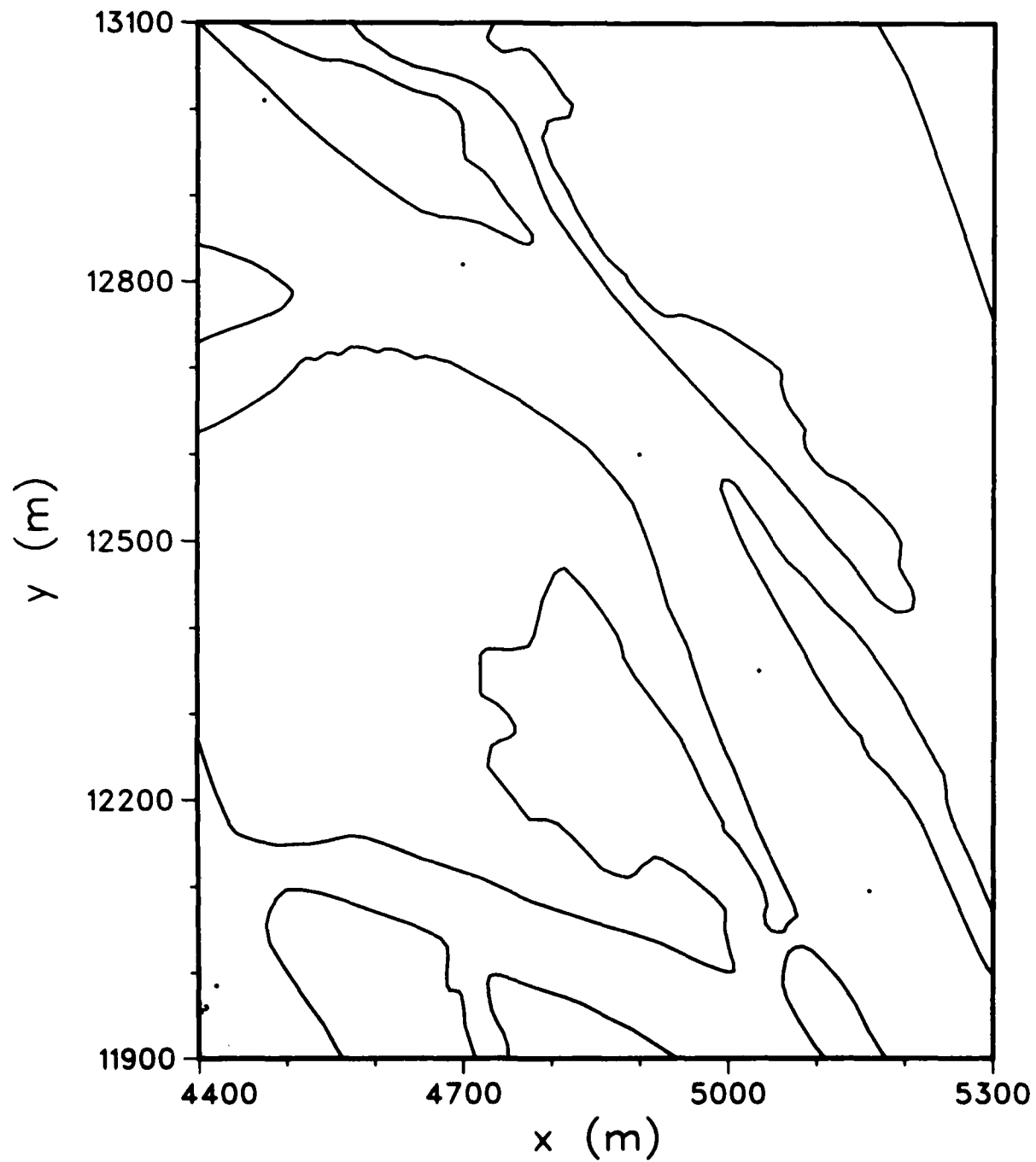
**FIGURE A.8 Bottom Sampling Locations and Dyed Sand Counts in Region a of the Gordon's Ferry Site for Survey IX**



**FIGURE A.9 Bottom Sampling Locations and Dyed Sand Counts in Region b of the Gordon's Ferry Site for Survey IX**



**FIGURE A.10** Bottom Sampling Locations and Dyed Sand Counts in Region c of the Gordon's Ferry Site for Survey IX



**FIGURE A.11 Bottom Sampling Locations and Dyed Sand Counts in Region d of the Gordon's Ferry Site for Survey IX**



**APPENDIX B**  
**WHITNEY ISLAND — DETAILED DATA**



AD-A162 084

MOVEMENT OF TAGGED DREDGED SAND AT THALWEG DISPOSAL  
SITES IN THE UPPER MI. (U) ARGONNE NATIONAL LAB IL  
ENERGY AND ENVIRONMENTAL SYSTEMS DIV..

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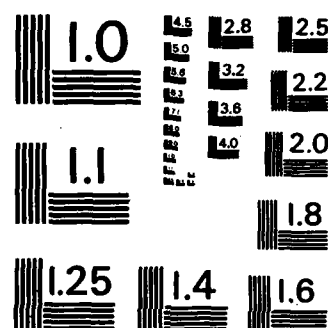
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MICROCOPY RESOLUTION TEST CHART  
NATIONAL BUREAU OF STANDARDS-1963-A

**APPENDIX B****WHITNEY ISLAND — DETAILED DATA**

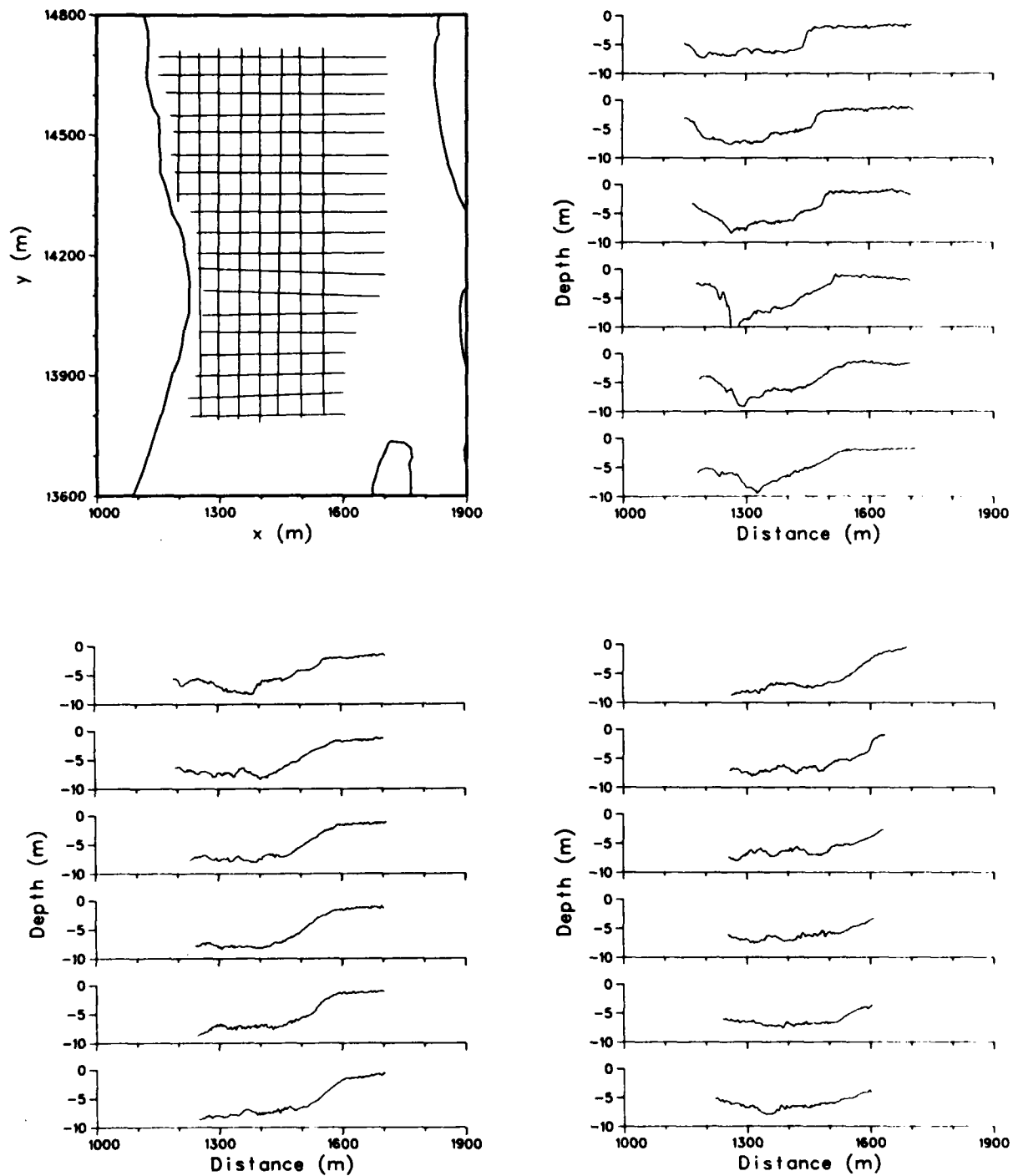
The results and some of the data from Surveys VI and VII at the Whitney Island site are presented and discussed in Sec. 4. The complete sets of bathymetric data and dyed sand data from each of these surveys are given in this appendix.

**B.1 BATHYMETRIC DATA FROM THE WHITNEY ISLAND DISPOSAL SITE**

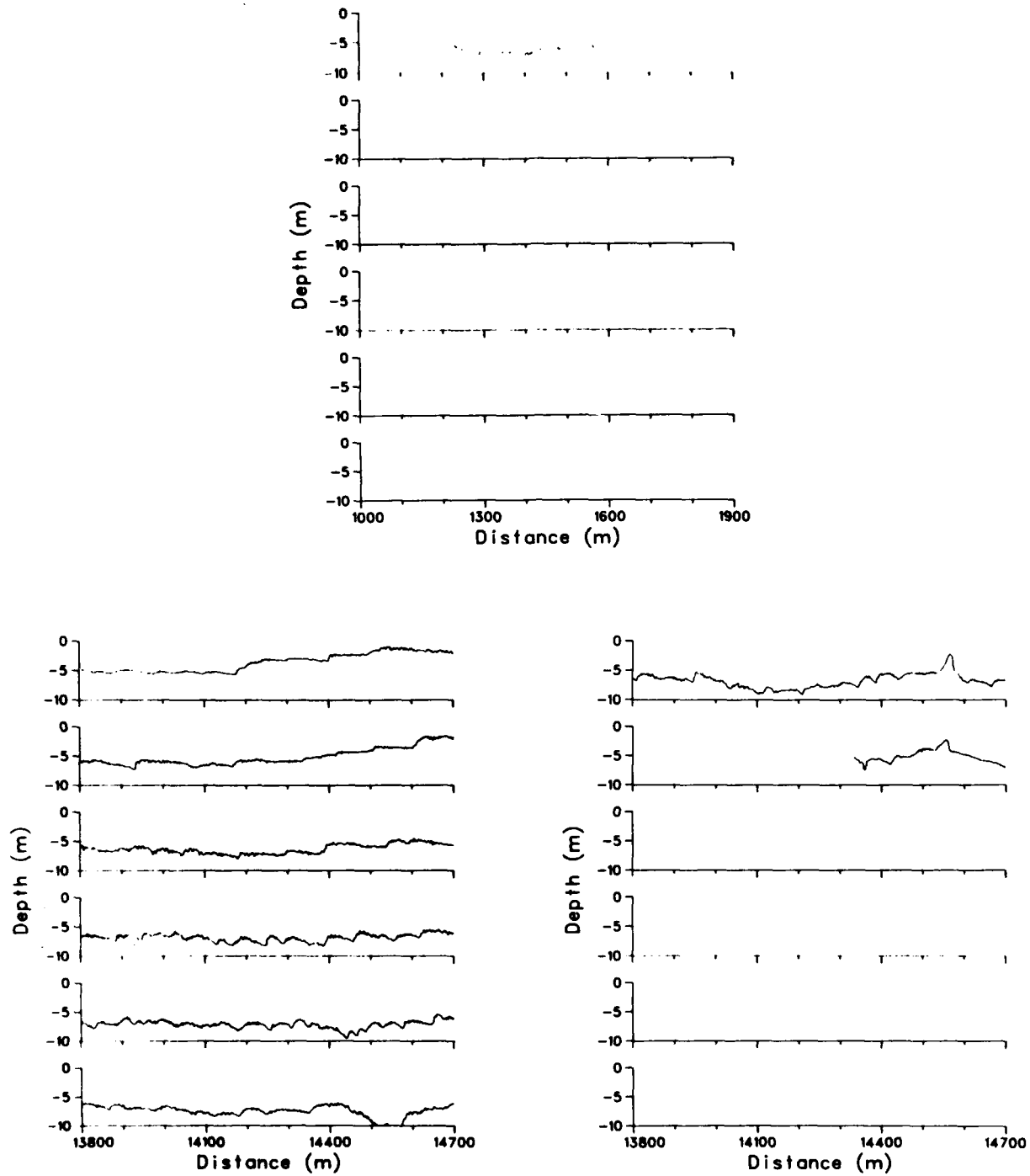
The complete bathymetric data from Surveys VI and VII at Whitney Island are presented in Figs. B.1-B.3. The approximate boat paths for each set of transects are shown in the upper left-hand quadrant of each figure. The bottom profiles for the transverse transects (approximately parallel to the x axis) are presented in sequence starting in the upper right-hand quadrant with the transect farthest upstream (northernmost) and proceeding downstream (southward). The profiles for the individual transects are plotted, starting from the Missouri (west) end of each transect. The bottom profiles for the longitudinal transects (approximately parallel to the y axis) are then presented in sequence, starting with the transect closest to the Illinois (east) shore and proceeding toward the Missouri (west) shore. The profiles for the individual transects are plotted, starting from the downstream (south) end of each transect.

**B.2 DYED SAND DATA FROM THE WHITNEY ISLAND DISPOSAL SITE**

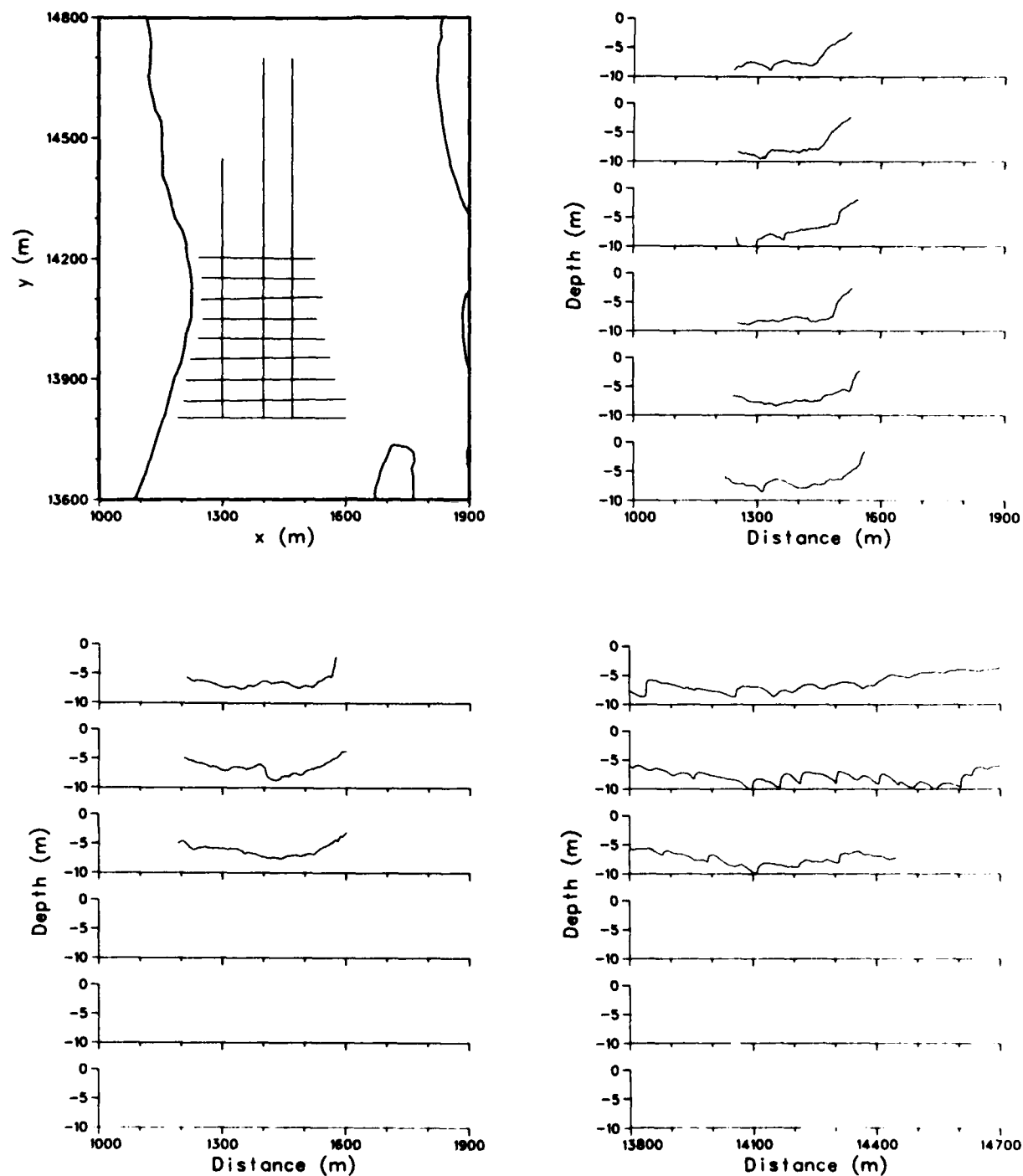
The study area was divided into three regions (a, b, and c) for presentation purposes as shown in Fig. B.4. Region a encompasses the original disposal area, region b includes the entrance to Stillwell Slough and the main-channel area between the disposal site and the slough entrance, and region c covers the upstream portion of Stillwell Slough and the main-channel area downstream of the slough entrance. The sampling locations for Surveys VI and VII are shown in Figs. B.5-B.10. The number of individual dyed sand grains, if any, observed in the photographs of the surface of the 23 x 23 cm sample tray illuminated by ultraviolet light is given adjacent to each sampling location.



**FIGURE B.1 Bathymetric Transects and Transverse Bottom Profiles for Survey VI at Whitney Island on November 30, 1983**

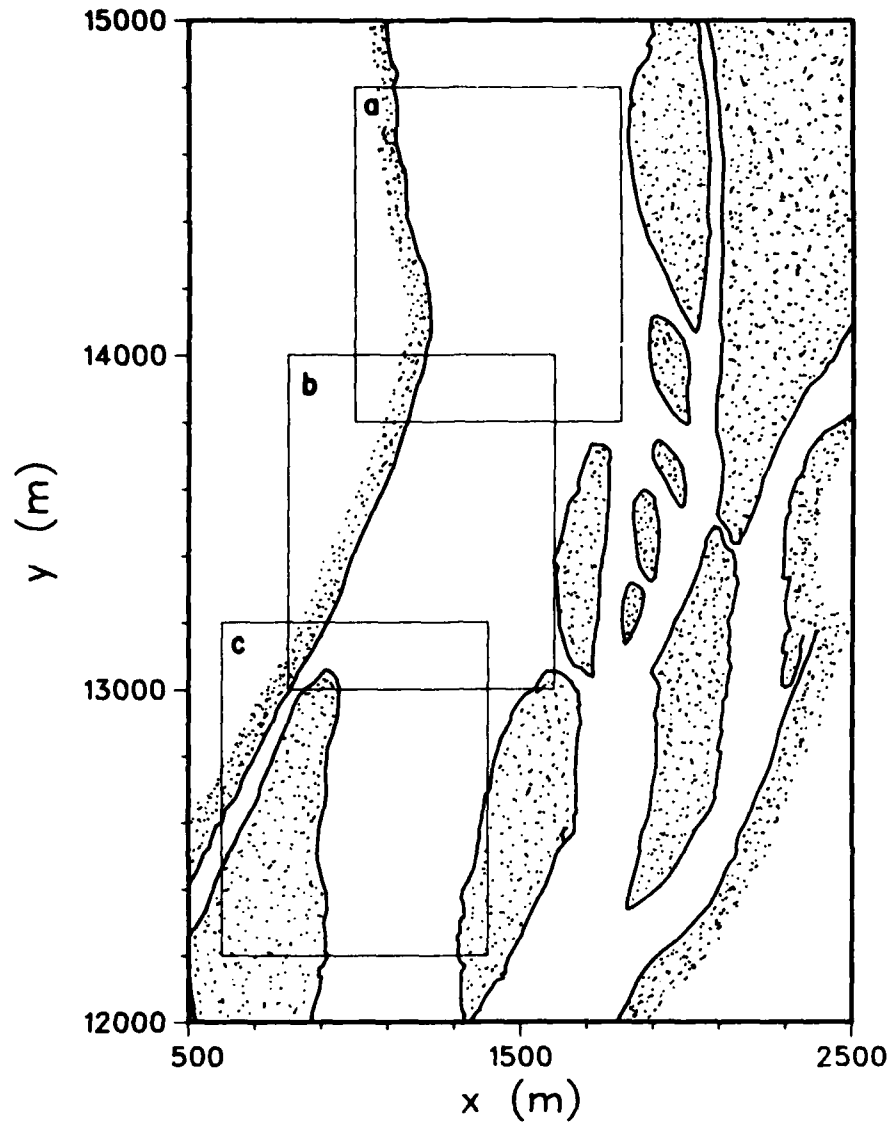


**FIGURE B.2 Transverse and Longitudinal Bottom Profiles for Survey VI at Whitney Island on November 30, 1983**

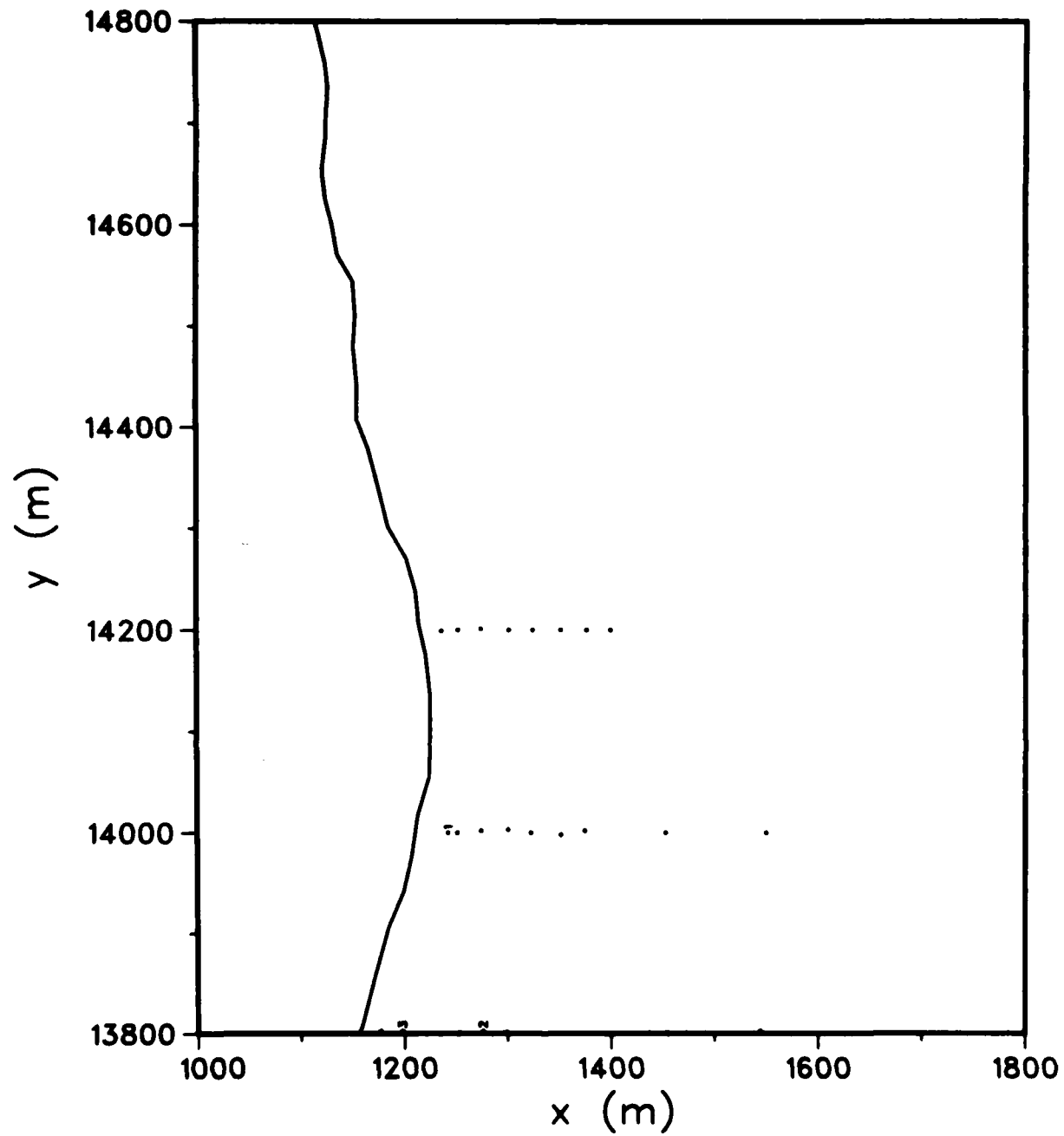


**FIGURE B.3 Bathymetric Transects and Transverse and Longitudinal Bottom Profiles for Survey VII at Whitney Island on October 3, 1984**

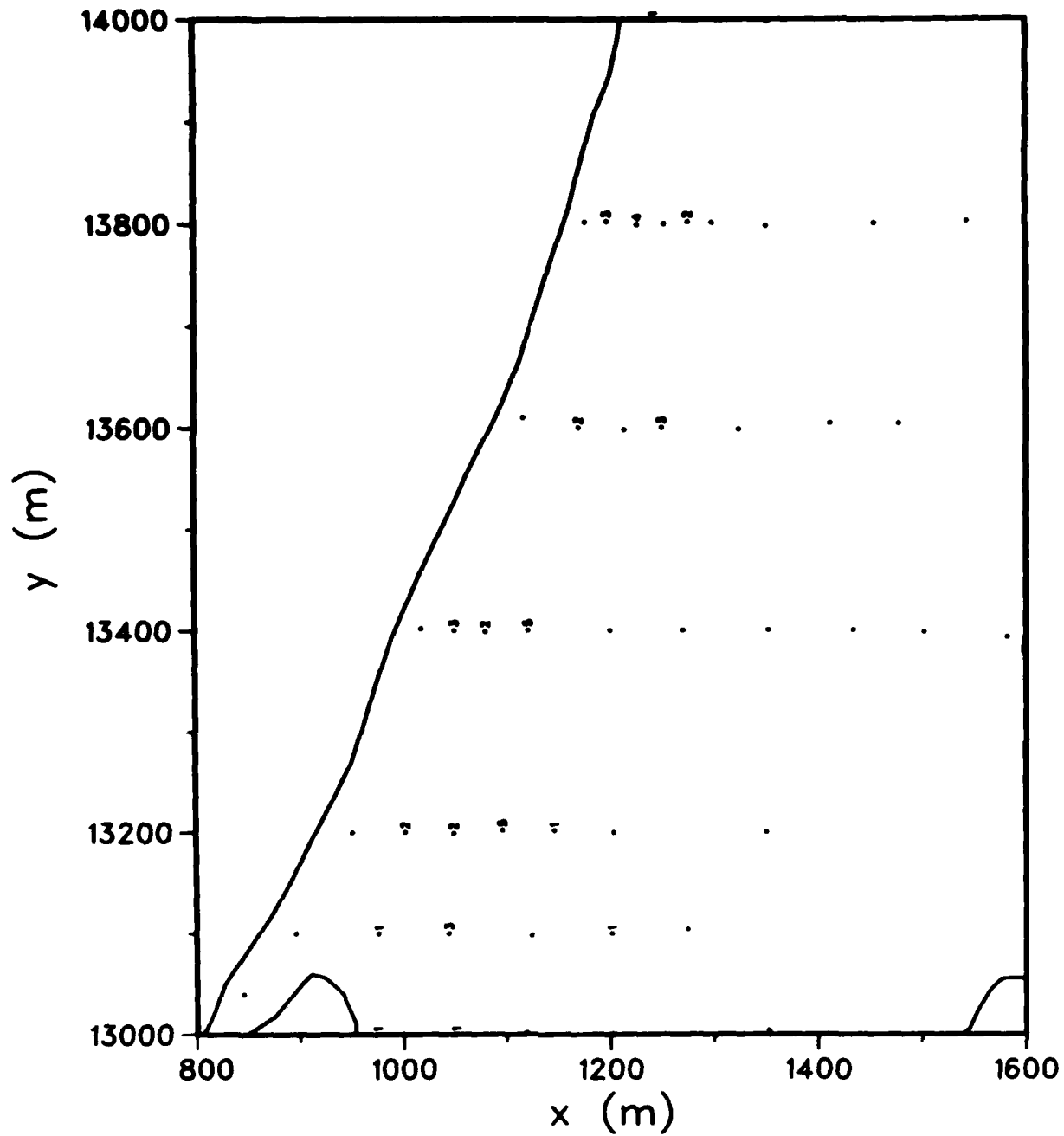




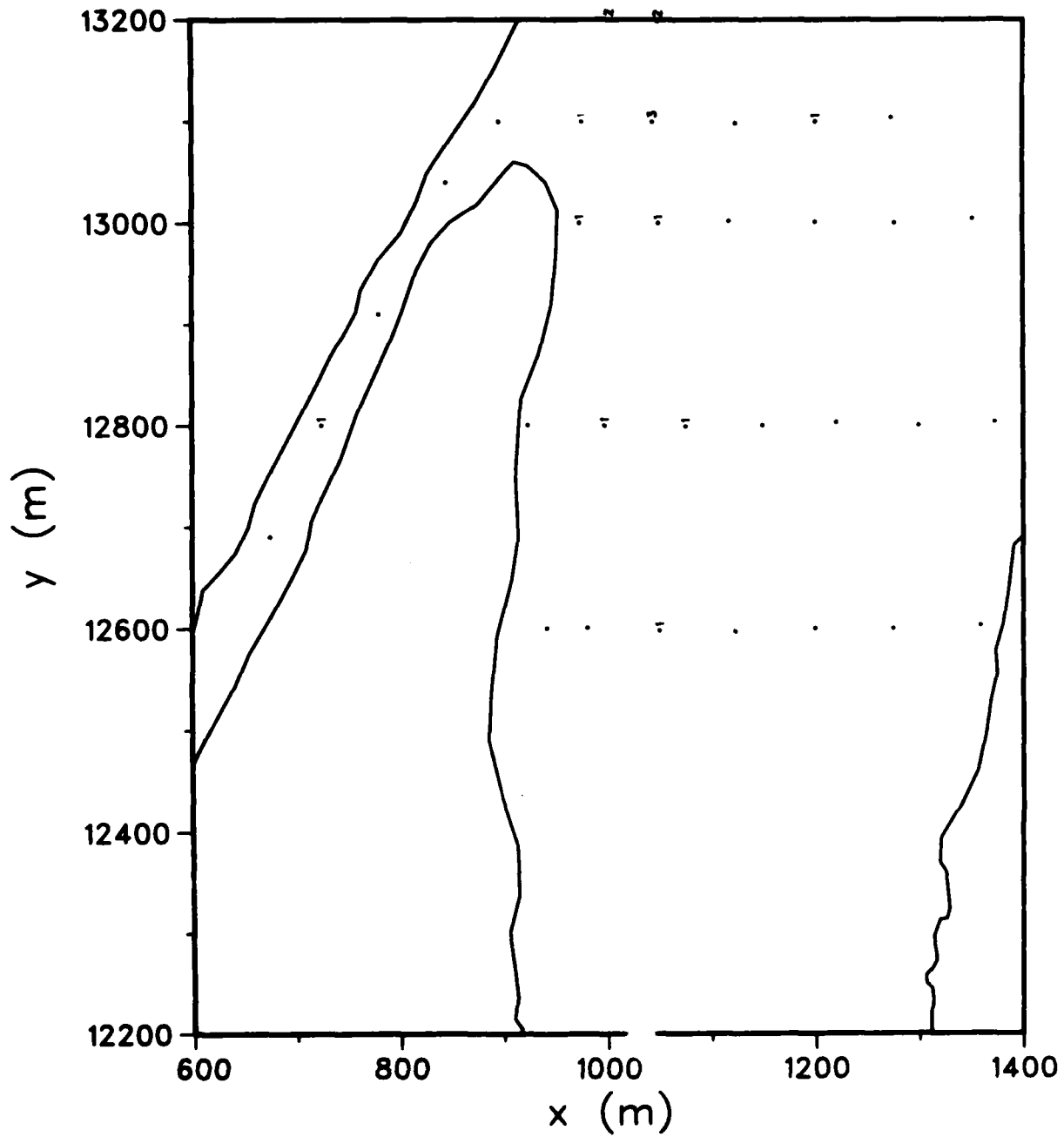
**FIGURE B.4 Whitney Island Site Showing the Three Regions (a, b, and c) where Bottom Samples Were Obtained**



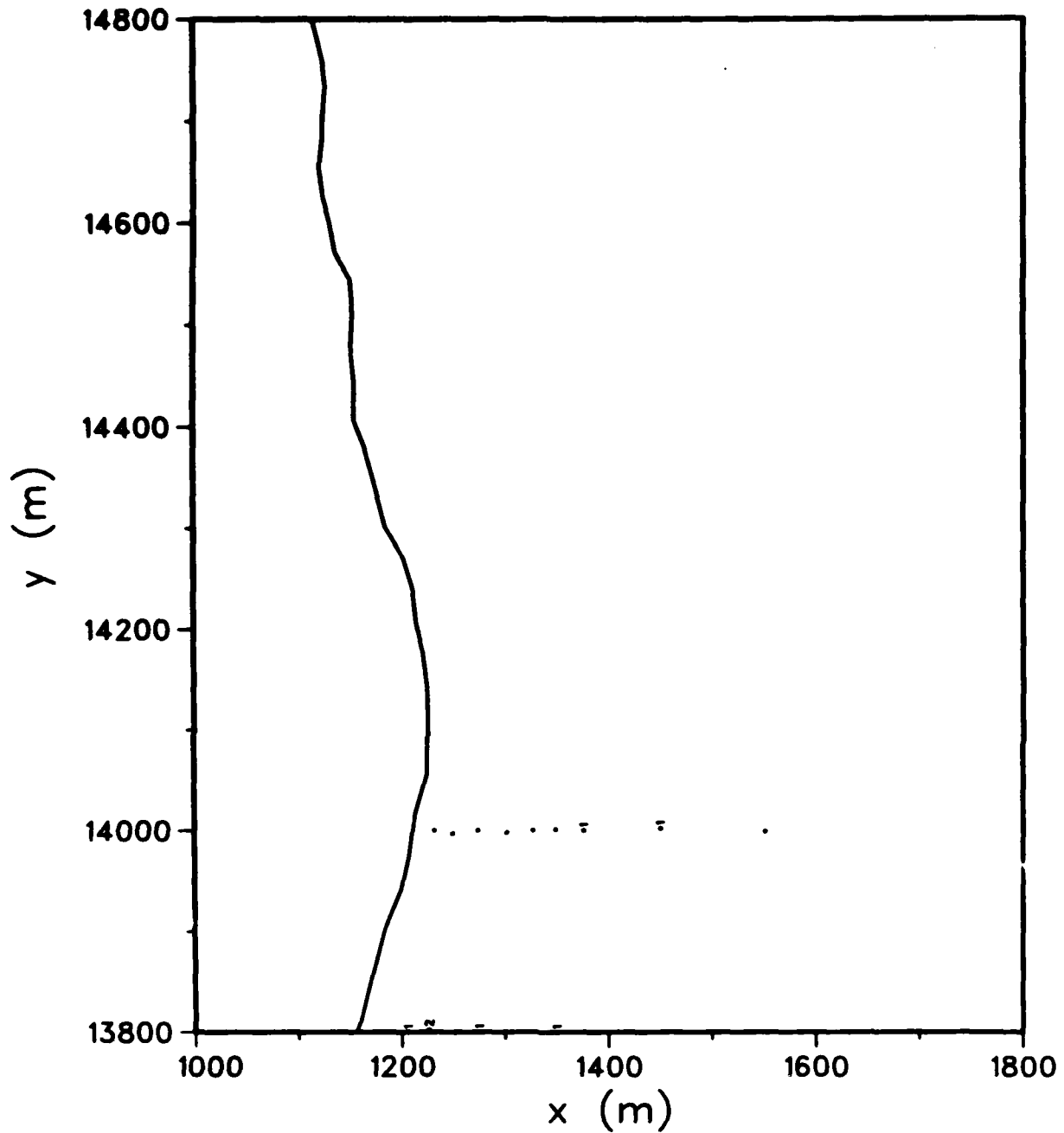
**FIGURE B.5 Bottom Sampling Locations and Dyed Sand Counts in Region a of the Whitney Island Site for Survey VI**



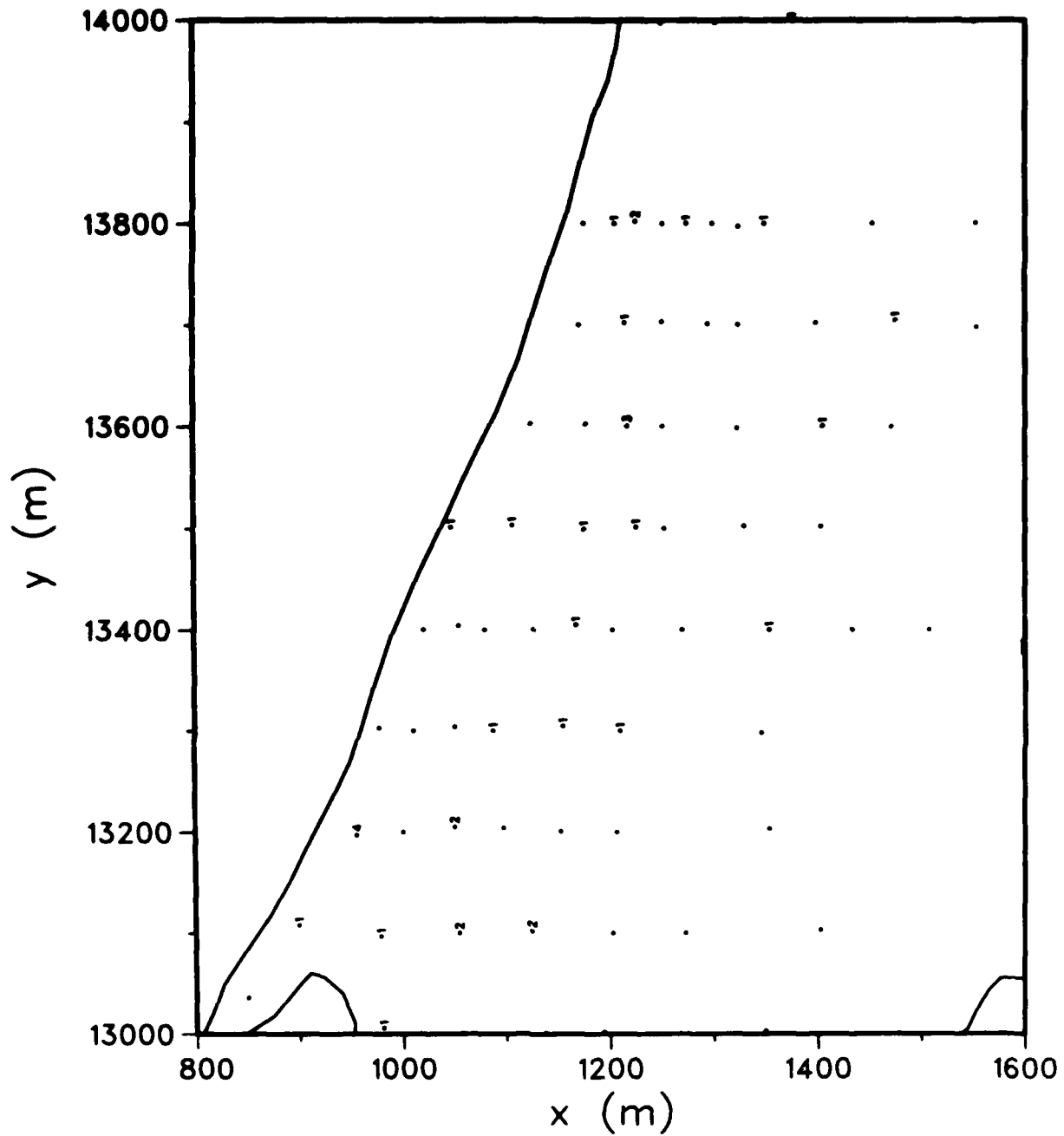
**FIGURE B.6 Bottom Sampling Locations and Dyed Sand Counts in Region b of the Whitney Island Site for Survey VI**



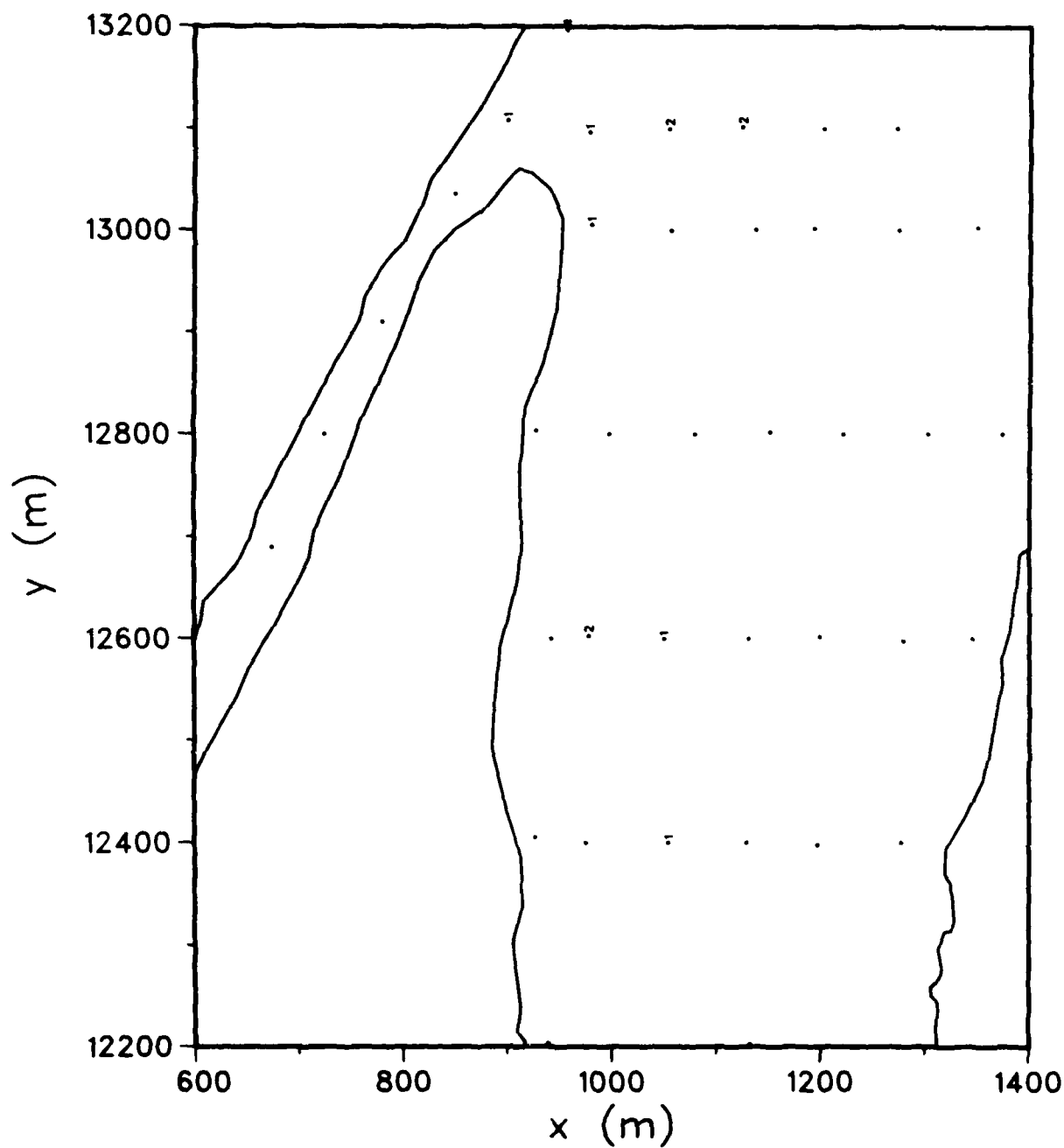
**FIGURE B.7 Bottom Sampling Locations and Dyed Sand Counts in Region c of the Whitney Island Site for Survey VI**



**FIGURE B.8 Bottom Sampling Locations and Dyed Sand Counts in Region a of the Whitney Island Site for Survey VII**



**FIGURE B.9 Bottom Sampling Locations and Dyed Sand Counts in Region b of the Whitney Island Site for Survey VII**



**FIGURE B.10 Bottom Sampling Locations and Dyed Sand Counts in Region c of the Whitney Island Site for Survey VII**

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